PROCEEDINGS

MAY 21 - 24, 2017

ISCRAM 2017

AGILITY IS COMING

MINES ALBI

14th International Conference on Information Systems for Crisis Response And Management

#AlbiThere4U

ISCRAM 2017

Edited by

Tina Comes, Frédérick Bénaben
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Proceedings of the International Conference on Information Systems for Crisis Response and Management

ISSN : 2411-3387

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ISCRAM 2017 Conference Proceedings

14^{th} International Conference on Information Systems for Crisis Response and Management

Introduction

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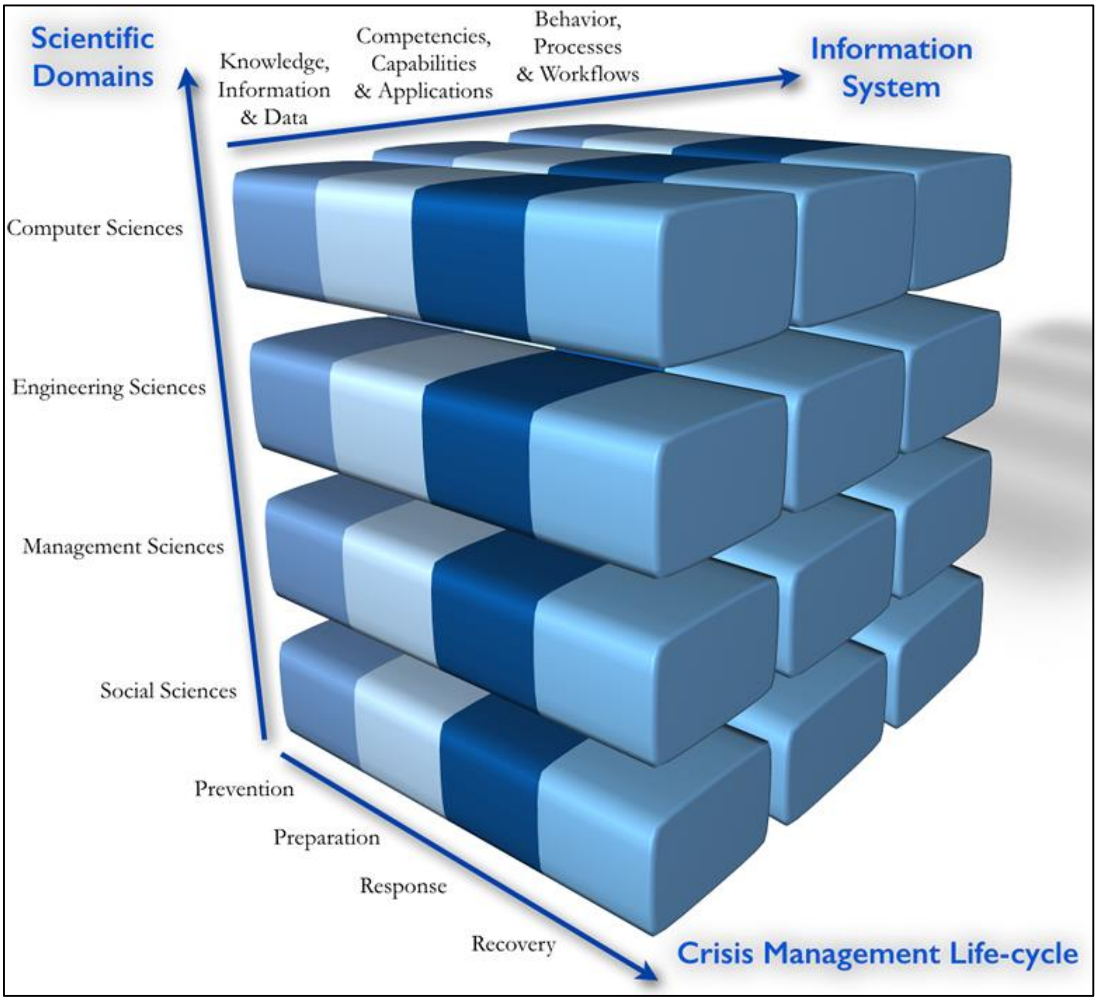
Message from the Program and Conference Chairs

Dear ISCRAM2017 Participant,

We are very pleased to present you this book of papers covering a wide range of topics across the different phases of the crisis management cycle.

Conference Theme & Structure: Agility is coming!

This year's conference theme is *"Agility is coming".* Through information systems, we have access to data in real-time. Agility enables responders and communities to react quickly to such information, set up collaboration mechanisms as needed, and jointly improve response and recovery processes and strategies. As such, agility is one of the keys for building more resilient societies.



In ISCRAM conferences, we have always been proud to facilitate knowledge exchange, foster discussions between researchers, practitioners and policy-makers. This year, to support this process, we have structured papers submission and reviewing along three dimensions:

- **Information Systems** covering knowledge, information and data; competences with associated capabilities and applications; and behaviour with associated processes and workflows.
- **Crisis Response and Management:** describing the well-known Life Cycle of crisis management, based on the four phases of prevention, preparation, response and recovery. This dimension is dedicated to help users and stakeholders to identify the results they could be interested in.
- **Scientific Domains of ISCRAM**: representing the range of scientific domains used to address the problems raised by the conference. This dimension shows the interdisciplinary and multidisciplinary characteristics of ISCRAM.

In the conference program, you will see that each day is dedicated to a theme: from prevention & preparedness on Monday, Response & Recovery on Tuesday, to Future Trends on Wednesday.

Reviewing Process

We would especially like to thank the track chairs, who oversaw and facilitated the reviewing process and recommended a decision for each paper to the Program Committee. As in the past years, we have received two types of papers (Research and Insight) that could be submitted as completed research (CoRe) or work in progress (WiPe). This is to cater for the needs of academics in different disciplines and practitioners in our community.

- **Research (theoretical) papers** were peer reviewed to the highest academic standards. The primary aim of an academic paper is to contribute to the scientific body of knowledge. Acceptance rates are competitive.
- **Insight (practical) papers** are intended to meet the needs of practitioners, professionals, experts, and policy makers by being peer reviewed to relevance in terms of practical standards. The primary aim is to give an insight into what problems arise during crises and how such problems can be solved in practice with the help of information systems.
- A **CoRe** paper reports a completed piece of work, including validation of the results. Only CoRe papers may apply for **Best Paper, Best Student Paper, and Best Insight Paper awards.**
- A **WiPe** paper aims at reporting part of a complete project. For example, it may describe a research plan, a literature survey, the design of an information system, the development and testing of software, user evaluation of developed software, a proposed new policy, and the like.

The acceptance rates are summarized in the Table below.

Submitted		Acceptance Rate	
CoRe	WiPe	CoRe	WiPe
52	125	35 %	60 %

ISCRAM2017 Events

Besides the paper submissions and presentations, we are proud to offer a series of workshops and tutorials. The pre-conference workshops on Sunday offer a venue to discuss emergent topics that do not fit a full ISCRAM track (yet). Tutorials are a venue to hands-on trial technology, methods and approaches. The doctoral colloquium is a place for PhD students to get feedback on their work and network with their peers.

Wednesday is dedicated to future trends and technology. We have the ISCRAM EU Symposium that brings together research projects on crisis response and management. With the demonstration and poster session, this will be an inspiring venue to discuss new trends and technologies in our domain.

Through these side events, we aim at fostering the ISCRAM community further, providing space for discussions and knowledge exchange.

ISCRAM2017 Conference - #AlbiThere4U

Organized in the world heritage city of Albi, the ISCRAM2017 conference intends to be an unforgettable event for three main reasons:

- **Social events**: Every day, from Sunday to Wednesday, includes a social event to make the most of the wonders of Albi and South-West of France.
- **Content:** The scientific program of the conference (workshops and tutorials on Sunday, three thematic days) aims to make the conference easy to follow and with great added value for academics, practitioners, and policy-makers.
- **People:** The organizing team is strongly committed to make this event great and enjoyable. We are expecting attendees from all around the world, representing a wide range of positions and competencies. This eventually makes the ISCRAM conference one of a kind.

Let us warmly welcome all of you on behalf of Ecole des Mines d'Albi-Carmaux, a school of IMT (Mines Telecom Institutes).

Thanks!

This conference is the effort of the ISCRAM community, and we would like to thank the track chairs and reviewers, the chairs of the side events, the conference organizers at the Ecole des Mines d'Albi for their dedication and effort. Now, we look forward to an exciting ISCRAM2017 Conference – *Agility is coming!*

Tina Comes, Matthieu Lauras, Aurélie Montarnal, Chihab Hanachi and Frédérick Bénaben

Program Chair & Co-Chairs

ISCRAM 2017 Keynotes

Humanitarian Operations: Past Achievements, Future Challenges and Research Opportunities

By Luk N. Van Wassenhove.
Professor — INSEAD Humanitarian Research Group

The Humanitarian caseload is increasing while funding is substantially decreasing. The nature and impact of crises is also changing. This creates serious tensions and a need to reflect on recent advances in research. What has been relevant and impactful? Are we dealing with the major issues and providing answers to practitioners? At the same time, technology now allows us to analyse situations and do things that were impossible only half a dozen years ago. How can these new technologies be better integrated and used? How can developments from other disciplines allow humanitarian practitioners to do more with less in these resource-scarce times? The field of humanitarian operations is in great flux and organizations need help in facing the rapidly changing world of providing aid to the ones in need.

The presentation will not attempt to cover all developments for the simple reason that I am not competent for that. However, I can share with you my own research work and experience in collaborating with a set of humanitarian organizations. I hope to convince you that this is an exciting field of research with lots of relevant multi-disciplinary problems where we can make a substantial impact.

Professor Van Wassenhove's research focus is on closed-loop supply chains (product take-back and end-of-life issues) and on disaster management (humanitarian logistics). He is the author of many award-winning teaching cases and regularly consults for major international corporations. He recently co-edited special issues on humanitarian operations for the Journal of Operations Management, the Production and Operations Management Journal and the European Journal of Operational Research.

In 2005, Professor Van Wassenhove was elected Fellow of the Production and Operations Management Society (POMS). In 2006, he was the recipient of the EURO Gold Medal for outstanding academic achievement. In 2009 he was elected Distinguished Fellow of the Manufacturing and Services Operations Management Society (MSOM), and received the Lifetime Achievement Faculty Pioneer Award from the European Academy of Business in Society (EABIS) and the Aspen Institute. In 2013 he has been recognized as an Honorary Fellow of the European Operations Management Association (EUROMA).

Professor Van Wassenhove is a past-president of the Production and Operations Management Society. In 2011 he was elected member of the Royal Flemish Academy of Sciences. At INSEAD he holds the Henry Ford Chair of Manufacturing. He also created the INSEAD Social Innovation Centre and acted as academic director until September 2010. He currently leads the INSEAD Humanitarian Research Group.

Does “fake news” change the social media equation? Online rumors, conspiracy theories and disinformation in the context of crisis response.

By Kate Starbird
Assistant Professor - Human Centered Design & Engineering (HCDE), University of Washington

Social media are now an established feature of crisis response. People—including emergency responders, members of the affected community, and remote onlookers—are repeatedly turning to platforms such as Facebook, Twitter and Snapchat to seek and share information about crisis events. However, there remain significant challenges to the utility of social media in this context—including rumors and misinformation. Crisis responders repeatedly cite a fear of misinformation as a reason to be wary of utilizing social media in their work. On the other side of the spectrum, social media evangelists have argued that the “self-correcting crowd” will consistently identify, attack, and neutralize misinformation. Over the last few years, my collaborators and I have conducted extensive research on online rumoring during crisis events, in part focused on how rumors are corrected (or not). Recently, our work has revealed how a specific subsection of the alternative media ecosystem facilitates the spread of disinformation—in the form of conspiracy theories or “alternative narratives” about crisis events—via social media. This disinformation is often employed as part of a political agenda and poses new information security risks. In this talk, I’ll present some of the most significant findings of our research on rumoring, rumor correcting, and the intentional spread of disinformation online during crisis events and discuss some of the implications for emergency and humanitarian responders.

Kate Starbird is an Assistant Professor at the Department of Human Centered Design & Engineering (HCDE) at the University of Washington (UW). Kate's research is situated within human-computer interaction (HCI) and the emerging field of crisis informatics—the study of the how information-communication technologies (ICTs) are used during crisis events. Specifically, her work seeks to understand and describe how affected people, emergency responders and remote individuals come together online to respond to major crisis events, often forming emergent collaborations to meet unpredicted needs. Recently, she has also focused on how online rumors spread—and how online rumors are corrected—during crisis events. Kate earned her PhD from the University of Colorado at Boulder in Technology, Media and Society and holds a BS in Computer Science from Stanford University.

Mystery Keynote — The Dark Side of the Force: Not what you think !

By Master Professor
Master Professor - Villain & Sith Research Center, University of the Galactic Empire

Mystery

Don't worry, the Mystery Keynote Speaker is not a villain! (unless they are...)

But for reasons which nobody knows (including themselves...), we are not allowed to reveal their identity.

We know this is so frustrating but, be patient... the Mystery Keynote is coming, on Wednesday (maybe...). In the meantime, we encourage you to participate in the others keynotes, workshops, symposiums and tutorials.

Before we let you go, here is a clue on the Mystery Keynote Speaker's identity: The Mystery Keynote Speaker is a HE! (unless it's a SHE...).

ISCRAM 2017 Track Chairs

Population and Priority Needs in a Limited Access Crisis
Andrew Alspach, William Chemaly.

Analytical Modeling and Simulation
Christopher Zobel, Josey Chacko.

Command and control studies
Björn JE Johansson, Peter Berggren, Nicoletta Baroutsi.

Ethical, Legal and Social Issues
Caroline Rizza, Hayley Watson.

Monitoring and Resilience of Critical Infrastructure in the hyper-connected society
Angelos Amditis, Evangelos Sdongos, George Athanasiou.

Network Analysis and the systemic and critical assessment of infrastructures
Damien Serre, Christophe Viavattene.

Planning, Foresight and Risk analysis
Murray Turoff, Victor Banuls, Sébastien Truptil.

Protection Models For Complex Critical Infrastructures
Florian Brauner, Frank Fiedrich, Christopher Zobel, Wolfgang Raskob.

Resilience engineering and management
Vincent Chapurlat, Igor Linkov, Florian Steyer.

Social Media Studies
Amanda Lee Hughes, Roxanne Hiltz, Muhammad Imran, Linda Plotnick, Christian Reuter.

Operational applications and perspectives
Adrien Mangiavillano, Audrey Senatore.

Logistics and Supply-Chain
Adam Widera, Jacques Lamothe.

New Technologies for Crisis Management
Frédérick Bénaben, Agnès Voisard.

Prevention and Preparation
Chihab Hanachi.

Response and recovery
Matthieu Lauras.

Future trends
Tina Comes.

ISCRAM 2017 Symposiums

EU Project Symposium

Hayley Watson, Vitaveska Lanfranchi and Tim Clark

Doctoral Symposium

Anne-Marie Barthe-Delanoë and Fiona McNeill

ISCRAM 2017 Workshops

Transport and Logistics Management in Crisis Situations

Carsten Dalaff, Gaby Gurczik, Bernd Hellingrath and Adam Widera

Post-Crisis Damage and Needs Assessment of Buildings for Response, Reconstruction and Recovery Planning

Angelos Amditis, Evangelos Sdongos and George Athanasiou

Disaster Healthcare and Disaster e-Health

Dave Parry and Richard Scott.
Contributors: Tony Norris, Julie Dugdale and Jose Julio Gonzalez

ISCRAM Practitioners Workshop: Using scenario's as Crisis Information performance indicators

Gerke Spaling, Barry van het Padje, Mark Aukema, Willem Treurniet and Bart v Leeuwen

ISCRAM 2017 Tutorials

Visual Analytics with Social Media for Emergency Response

Suvodeep Mazumdar and Vitaveska Lanfranchi

ISCRAM 2017 Master Class

Practitioners' Master Class

Rob Peters, Gerke Spaling and Henk Djurrema

ISCRAM 2017 Round Tables

Round Table “Prevention & Prepardness”

- Colonel Jacob Graham (PSU) — Training Datasets- Information Requirements for Future Crisis
- Prof. Juanqiong Gou (BJTU) — Collaborative pre-control in railway risk prevention
- Eva Poujardieu (ALLIANZ) — The role of the insurance industry in loss prevention
- Prof. Valerie November (LATTS) — From the exercice (EU Sequana, March 2016) to the reality (Flooding in Paris in June 2016): what has been learned?
- Prof. Hamideh Afsarmanesh (UvA) — Establishing the base infrastructure and system - breeding environment - as a key enabler for fluid formation of crisis handling networks of organizations

Round Table “response & Recovery”

- Commandant Florent Courrèges (SDIS 81) — The french firemen functions in response and recovery- state of the art and future outlook
- Dr. Andrea Tapia (PSU) — Scanning the Landscape of Social Media for Disaster Response and Recovery
- Xavier Tytelman (CGI consulting) —Social media exploitation in crisis management
- Dr. Sebastien Penmellen Boret (IRIDES) — Supporting recovery through managing bodies and memorialisations during emergency response
- Prof. Luis Camarinha-Matos (UNINOVA) — The role of collaborative networks in crisis response and recovery

ISCRAM 2017 Best Paper Awards Nominees

Best paper awards Committee

Victor A. Bañuls (Chair), José H. Canós, Starr Roxanne Hiltz, Radmila Juric, Murray Turoff, Christopher Zobel

Nominees for the Best Student Paper Award

Linking up the last mile: how humanitarian power relations shape community e-resilience
by Femke Mulder, Kees Boersma (elected Best Student Paper)

Social Triangulation: A new method to identify local citizens using social media and their local information curation behaviors
by Rob Grace, Jess Kropczynski, Scott Pezanowski, Shane Halse, Prasanna Umar, Andrea Tapia

On Variety, Complexity, and Engagement in Crowdsourced Disaster Response Tasks
by Sofia Eleni Spatharioti, Seth Cooper

Nominees for the Best Insight Paper Award

Managerial Challenges in Early Disaster Response: The Case of the 2014 Oso/SR530 Landslide Disaster
by Hans Jochen Scholl, Sarah L Carnes (elected Best Insight Paper)

Embedding Unaffiliated Volunteers in Crisis Management Systems: Deploying and Supporting the Concept of Intermediary Organizations
by Veronika Zettl, Thomas Ludwig, Christoph Kotthaus, Sascha Skudelny

Challenges for critical infrastructure resilience: cascading effects of payment system disruptions
by Joeri van Laere, Peter Berggren, Per Gustavsson, Osama Ibrahim, Björn Johansson, Aron Larsson, Towe Lindqwister, Leif Olsson, Christer Wiberg

Nominees for the Best CoRe Paper Award

Evaluation of Conversion to Quake-Resistant Buildings in Terms of Wide-Area Evacuation and Fire-Brigade Accessibility
by Takuya Oki, Toshihiro Osaragi (elected Best CoRe Paper)

Public expectations of social media use by critical infrastructure operators in crisis communication
by Petersen, Laura; Fallou, Laure; Reilly, Paul; Serafinelli, Elisa

Automatic Image Filtering on Social Networks Using Deep Learning and Perceptual Hashing During Crises
by Dat Tien Nguyen, Firoj Alam, Ferda Ofli, Muhammad Imran

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by Bañgate, Julius M.

Geographic information sharing for crisis management
by Cochery, Romain

Visual Analytics for Crisis Management
by Dusse, Flavio

Managing Flood Disasters
by Fertier, Audrey

Designing a Digital Neighborhood Watch
by Grace, Rob

Social Media Analytics for Emergency Management
by Marbouti, Mahshid

Formalization, Evaluation of non-functional for system of system engineering: Application to Resilience
by Moradi, Behrang

Information Network Power in Humanitarian Settings
by Mulder, Femke

Domain-Aware Matching in Emergency Response Scenarios
by Quesada, Francisco Jose

Challenges in Decision Support for Humanitarian Logistics Distribution in Large-Scale Disasters
by Rahman, Mohammad Tafiqur

How ICT can Facilitate Collaboration between Individuals and Organizations to achieve a Sefer and more Resilient Society
by Ramsell, Elina

Effective and Efficient Transportation of Sensitive Products Using Physical Internet Principles and Process Mining
by Schoen, Quentin

Usability of disaster apps: Insights from the app markets
by Tan, Marion

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by Norris , Tony; Parrym , Dave; J Gonzalez, Jose; E Scott, Richard; Dugdale,Julie; Khazanchi, Deepal

Twitter-based T-@npi Safety Confirmation System for Disaster Situations
by Abe, Mariko; Manaka, Ayami; Uchidam, Osamu; Utsu, Keisuke

Collection of Disaster-related Twitter Posts by Focusing on Posts Tweeted after Retweeting News Post of Kumamoto Earthquake
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An emergency group decision making method based on prospect theory
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Motivation and Participation of Digital Volunteer Communities in Humanitarian Assistance
by Fathi, Ramian; Fiedrich, Frank

A Case Study of Government Social Media Communication Strategies During a Mass Protest Incident in China
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Ontology-based Semnantic Health Resource Knowledge Base Development for Crisis Preparation
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DITS & DIMS 2: Disaster-related Information Tweeting and Mapping System Version 2
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Crisis Management for critical infrastructure's (CI) in the scenario of flooding
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Ginkgo: a Web Application to Support Information Sharing during a Post-Nuclear Accident Phase
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Population and Priority Needs in a Limited Access Crisis

Unpacking Data Preparedness from a humanitarian decision making perspective: toward an assessment framework at subnational level

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ABSTRACT

All too often the collection as well as analysis of data for humanitarian response only starts once a disaster hits. This paper proposes a framework to assess Data Preparedness on five dimensions: Data Sets, Data Services and Tooling, Data Governance, Data Literacy, and Networked Organizations for Data. We demonstrate for one dimension, i.e. Data Sets, how it can be quantified. First step is to determine which Data Sets must be collected before a disaster strikes so that as many as possible decision-makers' information needs are covered. Subsequently, a *Data Sets Preparedness Index* can be calculated based on Completeness, Recency and Accuracy & Reliability. We tested the index for Malawi and The Philippines and show how it can be used to direct data collection and determine when data analysis for e.g. predicting severity becomes meaningful. The index can be modified for reporting on global policies such as the Sustainable Development Goals.

Keywords

Data preparedness, humanitarian response, information requirements.

INTRODUCTION

Humanitarian decision-makers are working in stressful, high-pressure conditions where information is often lacking, distorted or uncertain. These conditions are known to introduce or enforce biases (Comes, 2017): cognitive biases resulting from simplifications to deal with complex problems and/or motivational biases resulting from the desire for a specific result. Examples are overestimating the number of affected people to push funding in a certain direction or underreporting for political reasons. The availability of accurate, reliable and timely information can reduce these biases and lead to improved decision making. It is therefore essential to know what the decision-maker's information needs are (Gralla et al, 2015). A case study on the 2014 floods in Bangladesh (van den Homberg et al., 2016) identified seven clusters with in total 71 information needs. This study did not only identify the information needs, but also mapped the data sets that became available from the start of the floods onwards, on the needs. 15 data sets with in the order of 40 to 60 indicators each were identified and they could meet only 27% of the information requirements in time (and 62% if timing constraints were not considered). This data and information gap enhances the biases in humanitarian decision making.

The rapidly changing and new information environment consisting of mobile services, social media, crowdsourcing and collaborative digital spaces offers several opportunities to narrow this gap as much as possible both before and during a disaster. One can more easily engage with communities and collaborate among different stakeholders. Governments can use the new digital technologies to open and share their data. Humanitarian donors push their recipients to do so as well using International Aid Transparency Initiative (IATI). Increasingly paper-based processes get digitized. These trends lead to a rapid increase in availability of data. In addition, the key global agreements that entered into force in 2015, i.e. the Sendai framework for Disaster Risk Reduction (DRR), the Paris Climate Agreement and the Sustainable Development Goals (SDGs), all require data collection on a number of indicators of which several are relevant also for humanitarian contexts.

Data Preparedness will be pivotal for seizing these new opportunities. We define Data Preparedness as all activities, that can be done before a disaster hits, to pre-stage data with sufficiently high data quality (that matches the prospective information needs of responders) and to develop capacities to collect data on affected communities and areas once a disaster hits to ensure a timely, efficient, and effective response. Data Preparedness can be considered an element of information management preparedness. OCHA defined already in 2009 an information management preparedness matrix, that covered general preparedness, capacity, data standards, data sets and tools and needs assessments (OCHA ROAP, 2009). Raymond and Al Achkar (Raymond and Al Achkar, 2017) proposed a data preparedness cycle, departing from the risks that the use of new technologies and data poses. The cycle has therefore a strong emphasis on legal, ethical and regulatory rules and norms. However, there is not yet to the best of our knowledge a Data Preparedness Framework that can be used to assess and quantify the level of data preparedness and that has been tested in practice.

METHODOLOGY

The objective of this paper is to develop such an assessment framework and test it in practice. It should be possible to apply the framework to an individual organizational but also to the humanitarian ecosystem of a country. Our methodology consists of desk research combined with case studies on typhoons in The Philippines and floods in Malawi. The case studies combine remote with in-country activities. The remote activities involved the organization of mapathons as part of Missing Maps and identifying data providers and data sharing platforms. For the Philippines, the in-country activities consisted of 32 interviews as part of an MSc study (van Lint, 2017) and a Surge Information Management Support deployment to Manila shortly after Typhoon Haima at the end of 2016, whereby feedback from humanitarian decision-makers of The Philippines Red Cross and OCHA was obtained. The in-country activities in Malawi consisted of a Data Preparedness Mission in February 2017, whereby a workshop was held within the Malawi Red Cross. Over 20 stakeholders (mainly government and NGOs) were interviewed and one week of mapping with about 15 enumerators was organized.

The research described is part of a larger Data Preparedness project led by The Netherlands Red Cross 510 initiative. 510 aims to drive the smart use of (big) data for faster and more (cost) effective humanitarian aid. The team works with knowledge institutes, private sector and other NGOs to ideate, research, implement and scale up new data-driven humanitarian aid innovations and to increase the capacity in the sector to work with and understand data. In this project, subnational disaster management data on several hazard prone developing countries is gathered and integrated into an easily accessible online dashboard, i.e. the Community Risk Assessment tool. This tool feeds into another tool that predicts severity and priority areas for humanitarian aid.

The outline of the paper is as follows. In the next section, we present the framework components at a general level. Subsequently, we focus on one component, i.e. the Data Sets. We describe how one can determine which data to collect and collate and develop, subsequently, a method to numerically measure progress. This method is applied for The Philippines and Malawi. We discuss these first test results and describe the implications for further use. Future work aims at developing an assessment framework for the other four components.

A FRAMEWORK FOR DATA PREPAREDNESS

Our framework for Data Preparedness consists of five components. For each component, we describe a set of questions that can be answered at an organizational or ecosystem level. We used this set of questions also in an interactive round table session, where groups of people rotate from one table to another, dealing at each table with one of the components.

Data Sets: Which data in relation to disaster management does your organization collect? Do you use a framework with indicators for this and what are your information needs? Which gap is there between your information needs and the data that is available to you? Do you have an overview of those data providers that will be important for you once a disaster strikes? For example, during the Typhoon Haiyan the international community did not have the automatic reflex to request data on cities from mayors.

Data Services and Tooling: Which services does your organization offer based on its data sets? Which tooling (software, hardware, but can also be paper-based) does your organization use to collect, analyze, and share data? Which tooling does your organization use for collaboration with other organizations and/or dissemination (like geospatial sharing platforms and collaborative digital tooling)?

Data Literacy: Do you have training programs for your employees in relation to data? Do you face obstacles in terms of lack of data literacy at several hierarchical levels within your organization? How do you assess the level of data literacy within your organization or possibly also of the partners you work with? Do you have an HR policy that attracts data literate staff?

Data Governance: What is the mandate of your organization in terms of data for disaster management and/or the business rationale? Do you have specific guidelines in place in relation to data collection, analysis and sharing? How do you safeguard privacy and ensure sensitive data is handled responsibly? How are data harms prevented from occurring?

Networked Organizations for Data: With which organizations do you coordinate or collaborate in terms of data? With which organizations do you share data or from which organizations do you get data? Do you have an open data policy and are you actively sharing data online? Have you reached agreements with others for datasets that cannot be shared openly? We note that these latter points overlap with Data Governance.

Table 1 Defining the different components when going from the preparedness to the response phase

Data Preparedness Component	Preparedness	Response
Data Sets	Framework: Risk indices More stable data, mostly secondary data	Framework: Crisis impact and Operational Environment indicators Highly dynamic data, mostly primary data
Data Services and Tooling	Services: early warning, identifying most vulnerable and hazard prone areas Tooling: Geospatial sharing platforms, formal communication channels (email, phone), mobile data collection, cloud based file sharing, dashboard technologies for data analysis/visualization.	Services: Identifying priorities: areas and people most affected. Tooling: similar, but for communication more informal, instant messaging and more use of collaborative digital spaces.
Data Literacy	Formal capacity building trajectories within organizations can be set-up and data champions appointed. Capacity building in assessment methodologies of especially the local actors is essential for obtaining granular data. Data collaboratives organize open data events, data uploading sessions as well as peer-to-peer learning.	High rotation of staff and the emergence of actors new to the humanitarian field. This requires an agile approach to learning and capacity building in different contexts to get people up to speed quickly.
Data Governance	Fundamental issues of data governance can be addressed. Formal, legal and regulatory data sharing frameworks can be developed.	Pragmatic, ad hoc solutions might be used. Risks for data harms might get aggravated.
Networked Organizations for Data	Data Collaborative More formal and long term network. Majority of national and local stakeholders involved.	Coordinated Data Scramble. Largely informal, flexible, short-term. Majority of international humanitarian organizations in case of level 3 disaster

Table 1 shows how the meaning of each of the components evolves when going from the preparedness to the response phase by giving a few examples. While for sudden onset disasters the preparedness phase is truly disparate from the response phase, for protracted and slow onset crises this distinction becomes more arbitrary. The table indicates that for both slow and sudden onset disasters, the data preparedness components are part of a continuum. The highly dynamic, new set of data on the crisis impact and operational environment in the response phase will be most valuable when integrated with pre-disaster more static baseline data. The

Networked Organizations for Data component describes the degree of coordination among multiple organizations. The term "Networked Organization" refers to organizations with a dominant focus on emergent dynamics in collaboration and less reliance on formal hierarchical structures (Treurniet, 2014). Typically, organizations in the response and preparedness phase are networked but do not have a formal structure around collecting, analyzing or sharing data for disaster management. For several of the larger disasters in the recent years, a Coordinated Data Scramble has been setup by the international community (Campbell 2016; Verity 2016) in the response phase. These scrambles rely on *contingent coordination* (Herranz, 2008), where some opportunistic directive influence guides network behavior, but reliance on emergent behavior is still quite high. After the response phase, this group can grow into a Data Collaborative (Verhulst, 2015), a network of organizations that exchange data for disaster management with a network management regime that relies on *active coordination*. Active coordination implies a more deliberate design of the network, including its constituent partners as well as the interaction and incentive mechanisms among the partners (Herranz, 2008). Concretely this means that for example data sharing agreements have been signed or that a facilitator has been appointed. Treurniet and van Buul (Treurniet and van Buul, 2015) described how the level of information sharing depends on the dynamics and type of collaboration within these networked organizations. The information sharing can move from stovepiped data (sharing information via non-aligned reports across actors), shared data (a common frame of reference/uniform format for basic information exchange) to shared situation assessment (full common frame of reference/uniform format for all information exchange). We can use this matrix of level of information sharing versus level of collaboration to assess data preparedness on the Networked Organizations for Data dimension.

The framework is mostly useful for measuring data preparedness at output and -but to a lesser degree- outcome level. The framework cannot be used to determine the impact on sensemaking and decision making processes. Our underlying assumption is that data preparedness leads to data with higher quality in the response phase, which will debias the humanitarian decision making process. For example, the decision on where to place an operational hub for UN clusters in country can become more transparent by having a geographical assessment in place beforehand. In the remainder of this paper we zoom in on the first of the five pillars: Data Sets.

DATA SETS

Determining which data to collect and collate

As explained in the previous paragraph, a crucial part of data preparedness is pre-staging as many data sets as possible and making sure they match the information needs of responders.

Obviously, a first step is to make an inventory of the information needs for different disaster contexts. The Interagency Standing Committee (IASC) Assessment Task Force developed the Multi-Sector Initial Rapid Assessment framework (MIRA) and groups information needs into two pivotal categories, i.e. the Crisis Impact and the Operational Environment, with twelve subthemes (MIRA, 2015). Gralla et al. (Gralla et al., 2015) identified eight clusters of information requirements of field-based decision-makers along the response timeline, when going from the early stage of the response towards recovery. In the Bangladesh case that was introduced earlier (van den Homberg et al., 2016), the two main categories of MIRA were used to group the 71 information needs as identified through semi-structured interviews and focus group discussions. The cluster of Crisis Impact consisted of baseline information about the vulnerability and livelihood of communities in hazard prone areas, damage and needs assessments and information about the disaster situation such as which areas are inundated and how long the flood will last. The Operational Environment comprises coordination and capacity information as well as information on the degree of humanitarian access.

Second step is to acquire the corresponding data sets. Information requirements can be met by combinations of data sets; this is not a completely straightforward relationship. The IASC developed in 2010 *Guidelines Common Operational Datasets (CODs) in Disaster Preparedness and Response* (IASC, 2010). CODs are 'best available' datasets that ensure consistency and simplify the discovery and exchange of key data. The core CODs are Administrative Boundaries, Population Statistics, Humanitarian Profile. Country-specific CODs are a subset of the CODs that are specific to each country's risk profile. Examples included: datasets related to demographics, geography, infrastructure (structures that could be impacted or used during relief operations such as schools, health facilities and refugee camps) and activities. Whereas these guidelines are very useful to increase the interoperability of data sets and improve data sharing, they do not aim at providing a framework to bring the different data sets together in an insightful and coherent way. A risk framework can do so. Risks materialize into crisis impact and affect the operational environment. As an example, the number of people affected (part of Crisis Impact) has a direct relation with the number of people that are exposed (before the disaster hits). Similarly, the hospitals and doctors available in the disaster area (part of Operational

Environment) can be derived from the hospitals present in the area before in combination with how they were impacted. We have therefore decided to collect and collate data on the indicators of risk before a disaster hits. Given the mandate of humanitarian organizations, our focus hereby is at risk at the community level. As a matter of fact, most of the CODs can also be categorized under one of the risk components.

In recent years, many risk indices have been developed. Most of these indices consist of a weighted or unweighted combination of indicators measuring different components of risk, resilience, or vulnerability. The World Bank report, *Unbreakable, Building the Resilience of the Poor in the Face of Natural Disasters*, lists 13 of them (Hallegatte, 2017), where each index is developed with different or sometimes to some extent overlapping user groups and application domains in mind. For example, the World Risk Index (WRI, 2016), as developed by the Institute for Environment and Human Security, United Nations University, and the University of Bonn, seems to be mostly used for development, Climate Change Adaptation (CCA) and DRR, whereas INFORM, developed by the EU Joint Research Center and UN OCHA (INFORM, 2016), is mostly targeting humanitarian aid. At the community level, NGOs, Red Cross local chapters and other mostly local organizations do regularly Participatory Capacity and Vulnerability Analysis (PVCA) assessments. These give relevant information on some of the risk components, but the analyses are often not digitized and can be both quantitative and qualitative. PVCAs tend to be an instrument to raise awareness and build capacity at community level and are not so much an instrument to get very accurate numbers on risk.

The INFORM, WRI and PVCA report at different administrative levels. Whereas PVCA reports at the community level, the WRI and INFORM report at the national level. INFORM is now working on going towards subnational level under an EU ECHO grant that OCHA and UNDP have received at the end of 2016. INFORM's main components are Vulnerability, Lack of Coping Capacity, and Hazards & Exposure, see Figure 1. These three categories are always the same for several countries. At subnational level, specific indicators per component are determined per country based on a consultative process with key stakeholders and data providers. This allows integration of data at the subnational levels, from regional, provincial, municipal up to neighborhood level. We have therefore decided to create a Community Risk Assessment based off the INFORM framework. This Community Risk Assessment distinguishes itself from INFORM through its reach in terms of administrative levels and through its application in a prioritization model. The reach in terms of administrative levels is limited by the availability of data; Figure 1 shows which data sets are available (yes) or not (no) at administrative level 2. The prioritization model predicts high priority areas based on a combination of (open) secondary risk data on hazard prone areas, weather information on the imminent hazard (such as wind speeds and rain falls) and data from past similar disasters. It uses machine learning and data mining algorithms.

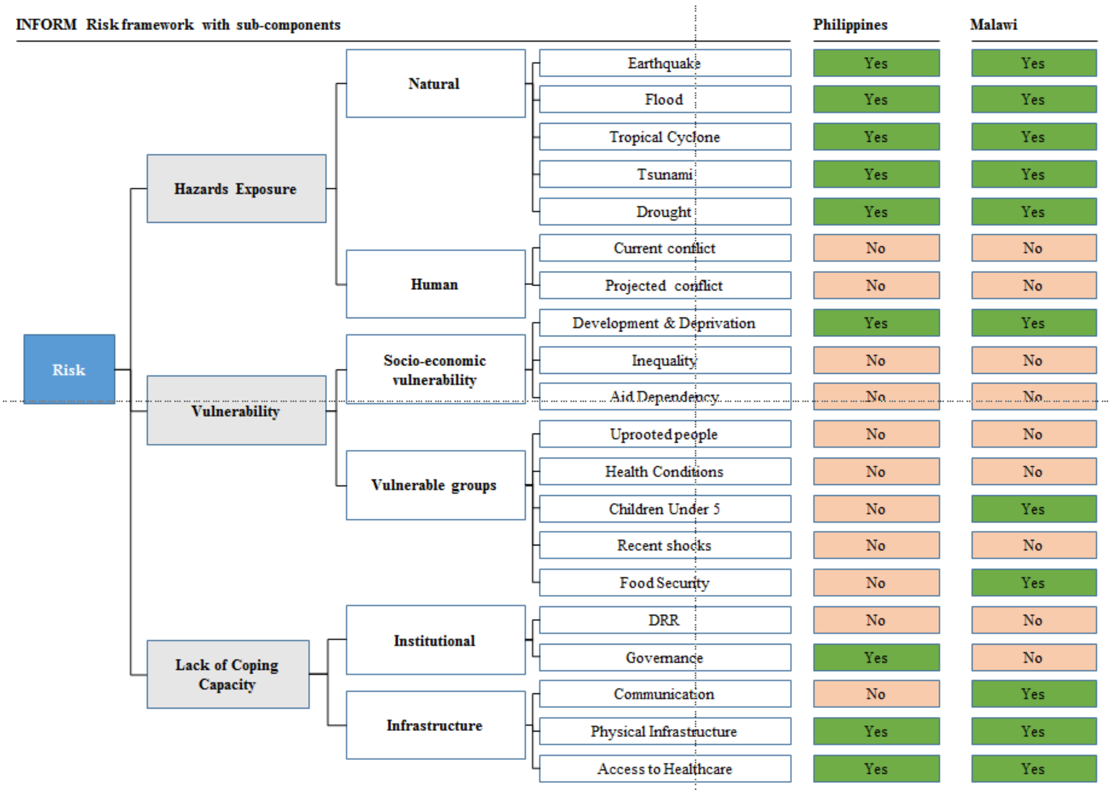

Figure 1 Indicator Framework inspired by INFORM with available data sources for Philippines and Malawi. Yes and No refer to whether the data was available at administrative level 2.

Calculating the Data Sets Preparedness Index

We develop a Data Sets Preparedness Index (DSPI) by selecting specific Data Quality dimensions. Several international organizations such as the UN, IMF and the EU have developed different data quality assessment frameworks. The Post2015 Data Test initiative (Post2015, 2014) drew from these frameworks to develop a Quality Assessment Framework specifically for the monitoring of SDGs. We extracted and transformed some of the indicators in this framework so that we would have a basic set to start with and that would be quantifiable, i.e. *Completeness, Recency* and *Accuracy & Reliability*. The formula for DSPI is as follows and will be explained in more detail below.

$$DSPI = Completeness * Recency * Accuracy \,\&\, Reliability$$

Completeness: The first component of the DSPI to consider is Completeness. If for each subcomponent (see **Erreur ! Source du renvoi introuvable.**igure 1) at least one data source is available then Completeness is defined as 100%. For each subcomponent i that has no corresponding data source in the considered country, the Completeness-score decreases, according to the weight of the subcomponent in the total risk-score. The weight of subcomponents towards a higher-level component is always divided equally. Hazards, Vulnerability and Coping Capacity each constitute one third of overall risk, Natural and Human Hazards each constitute 50% of overall Hazard, etc.

$$Completeness = \sum_i weight_i * I_i$$

where I_i is a function that results to 1 if datasource *i* is available and 0 otherwise.

Naturally, if the considered use case is different, the definition of Completeness will have to change accordingly. When collecting data on SDGs, Completeness will be defined by taking all considered SDGs and their corresponding indicators as a starting point. The principle of measuring completeness between 0% and 100% as is done here, will remain the same.

Granularity level: With the first component of the DSPI defined, it is insightful to take a step back and define the concept of granularity level. Namely, one can look at different levels to Data Preparedness. Some sources may be available on municipal level, while others are available only on provincial level. This means that when we are assessing Community Risk at a provincial level we will have more data sources and thus higher Completeness, then when we are assessing at a municipal level. Depending on the context, both perspectives can be relevant, and thus the Community Risk Assessment toolbox allows for various levels of administrative granularity. Correspondingly, the same goes for the Data Sets Preparedness Index. For each source, the deepest available granularity level is noted down, so that Completeness can be computed as a function of granularity.

$$Completeness(g) = \sum_i weight_i * I(g)_i$$

where *g* is granularity level, and $I(g)_i$ results to 1 if .data source *i* is available on granularity level *g* or deeper.

Recency: After completeness, a second very important criterion of a data source is its Recency. Recency is a combination of when the data set was last updated and how long a data set remains representative of the reality. The more recent the source is, the higher the Recency score should be. How long a data set remains representative can also be termed "retention period". Some data sets stay valuable longer than others. For example, the retention period of a source about the geospatial distribution of earthquake risk is generally deemed longer than the retention period of a research on Good Governance Index of local municipal government, which might very well have changed considerably after a new local government was elected. Scoring the retention period per source is a subjective matter. In our primary calculations, this was done to the best of our abilities. But in future applications of this framework, this can be determined more accurately for example through averaging expert opinions.

In conclusion, the more recent a data set is and the longer its retention period is, the higher the Recency score is. Mathematically, this is defined as follows for data source *i*.

$$Recency_i = Avg\left(\frac{\max(10 - years\ passed_i, 0)}{10}, \frac{\min(retention\ period\ _i, 10)}{10}\right)$$

The first part of this formula resolves to 1 if 'years passed = 0', so if the source is from 2017, and results in 0 if the source is more than 10 years old. The second part resolves to 1 if the retention period is 10 years or higher, while it resolves to 0 if the retention period is 0. The two parts are averaged out to get to the Recency score, which is again a score between 0 and 1 (i.e. between 0% and 100%). The total Recency score is again the weighted average of all individual Recency scores with the same weights as earlier used in the Completeness measure. Note that only Recency of available sources are included in this weighted average, so that incompleteness is not counted twice. It might be necessary at some stage to differentiate the cut-off timescales between indicators.

Accuracy & Reliability: Lastly, data sources can – independently from their Recency – also vary greatly in their Accuracy & Reliability (Post2015, 2014). In terms of source types, a census is generally considered more accurate than a survey for example, simply because it measures the entire population instead of a sample. Besides this, the Accuracy & Reliability can also be assessed by looking at the source and its publishing organization. This is currently a mostly qualitative assessment. In our preliminary calculations, we have done this to the best of our abilities by ranking each source on a scale from 1 to 5. Like the retention period, this part can be further formalized in future research by defining subcriteria, such as used in the Post2015 framework (Post2015, 2014) and by using expert opinions to assess these criteria. The 1-5 scale is subsequently linearly transformed to a 0-1 scale per source, after which the weighted average is taken to obtain the overall Accuracy & Reliability score. Note again that only Accuracy & Reliability of available sources is included in this weighted average, so that incompleteness is not counted twice.

Data Sets Preparedness Index: Finally, the three components of Data Preparedness are combined into the Data Sets Preparedness Index, also a score between 0 and 1. For granularity level g, this yields:

$$DSPI(g) = Completeness(g) * Recency * Accuracy \,\&\, Reliability$$

We use multiplicative aggregation here (versus taking the arithmetic mean for example), because in an ideal situation all three components should be equal to 1. If only 50% of the sources is available, and thus the Completeness score is 0.5, then we want the DSPI also to be 0.5 at most (with perfect Recency and Accuracy & Reliability). If on top of that, the Recency and Accuracy & Reliability are also not perfect, then this should further decrease the DSPI-score.

For interpretation purposes, some feeling for the magnitude of DSPI is insightful. For example, if all three components are average and have a score of 0.5 each, then the DSPI resolves to $(0.5)^3 = 0.125$. While this low score is justified, because there is a lot of progress to be made on three fronts, a score of 0.125 can be interpreted as reasonable.

Applying the Data Sets Preparedness Index

Calculation example: Table 2, 3 and 4 show results for the DSPI calculations for The Philippines and Malawi. For Malawi, 0 represents national level, 1 region level (there are three regions), 2 district level (28 districts) and 3 National Assembly constituency or Traditional Authority (TA) level (usually around 5 or 6 per district). For the Philippines 0 represents national level, 1 regions (17), 2 provinces/cities (81), 3 municipalities (1,489) and 4 barangays (42,029). If we look at the consolidated results in Table 4, we can see that the Completeness decreases when going down in administrative levels from 2 to 3 for Malawi and from 3 to 4 for The Philippines. Although indicators differ per country, the DSPI can be used to compare also across countries how far a country is in having sufficiently granular and qualitative data on their set of indicators. The index could then be used to track progress of countries in making sure they get more accurate, detailed, timely data on communities and in this way, we could link it more easily to indicators used in key global agreements such as Sendai and the SDGs or other models like INFORM.

Application: The above calculations lead to an immediate conclusion for the Community Risk Assessment toolbox. Namely, for the Philippines it is currently meaningful to develop the risk framework at administrative level 3 (municipal), but not yet at administrative level 4 (barangay) where the DSPI drops sharply. For similar reasons, in Malawi, the risk framework is for now developed only at administrative level 2 (the district level), but not yet at administrative level 3 (TA level), see Figure 2. In general, we have from these initial calculations derived an initial DSPI threshold level of 0.10. While rolling out the Community Risk Assessment toolbox to new countries, after the initial data scramble a DSPI is calculated. If this DSPI is lower than 0.10, the data preparedness is currently considered too low to meaningfully include the country.

Even though a higher DSPI is preferable to a lower one, the framework and calculation are still very insightful in case of the latter. First, the calculation is digitally stored and as new sources become available they can quickly be added, so that the progress can be monitored, and the "gap" between the current situation and the minimum threshold can be measured. Second, the bottom-up calculation of the framework also quickly gives insight into where the gaps are (see Table 3, which can even be expanded to one lower level of subcomponents as seen in Figure 1). All scores can easily be subdivided into the subcomponents of the risk framework, thereby giving focus to initiatives to bridge the gap.

Shortcomings: Some parts of this calculation, especially in the Recency and the Accuracy & Reliability part are not perfect yet and should be further developed. As such, they should in part be seen as an exemplary calculation to make the somewhat abstract concept of a DSPI more concrete, and as a starting point of further discussion.

Table 2 Calculation of the Data Sets Preparedness Index for administrative level 3 in The Philippines

Component	Completeness	Recency	Accuracy &Reliability	DSPI
Hazards & Exposure	0.50	0.70	0.60	0.21
Lack of Coping Capacity	0.58	0.39	0.63	0.14
Vulnerability	0.19	0.58	0.70	0.08
Risk	***0.42***	***0.54***	***0.63***	***0.14***

Table 3 Specification of DSPI per subcomponent for administrative level 2 in The Philippines

Component	Completeness	Recency	Accuracy &Reliability	DSPI
Hazards & Exposure	0.50	0.70	0.60	0.21
Natural	1.00	0.70	0.60	0.42
Human	-	-	-	-
Lack of Coping Capacity	0.58	0.39	0.63	0.14
Infrastructure	0.67	0.53	0.50	0.18
Institutional	0.50	0.20	0.80	0.08
Vulnerability	0.25	0.58	0.70	0.10
Socio-economic vulnerability	0.50	0.58	0.70	0.20
Vulnerable Groups	-	-	-	-
Risk	***0.44***	***0.54***	***0.63***	***0.15***

Table 4 Overview of the Data Sets Preparedness Index results for The Philippines and Malawi

	Philippines			**Malawi**	
Administrative level	**2**	**3**	**4**	**2**	**3**
Completeness	0.44	0.42	0.08	0.46	0.19
Recency	0.54	0.54	0.52	0.55	0.67
Accuracy &Reliability	0.63	0.63	0.63	0.61	0.60
DSPI (product)	***0.15***	***0.14***	***0.02***	***0.15***	***0.08***

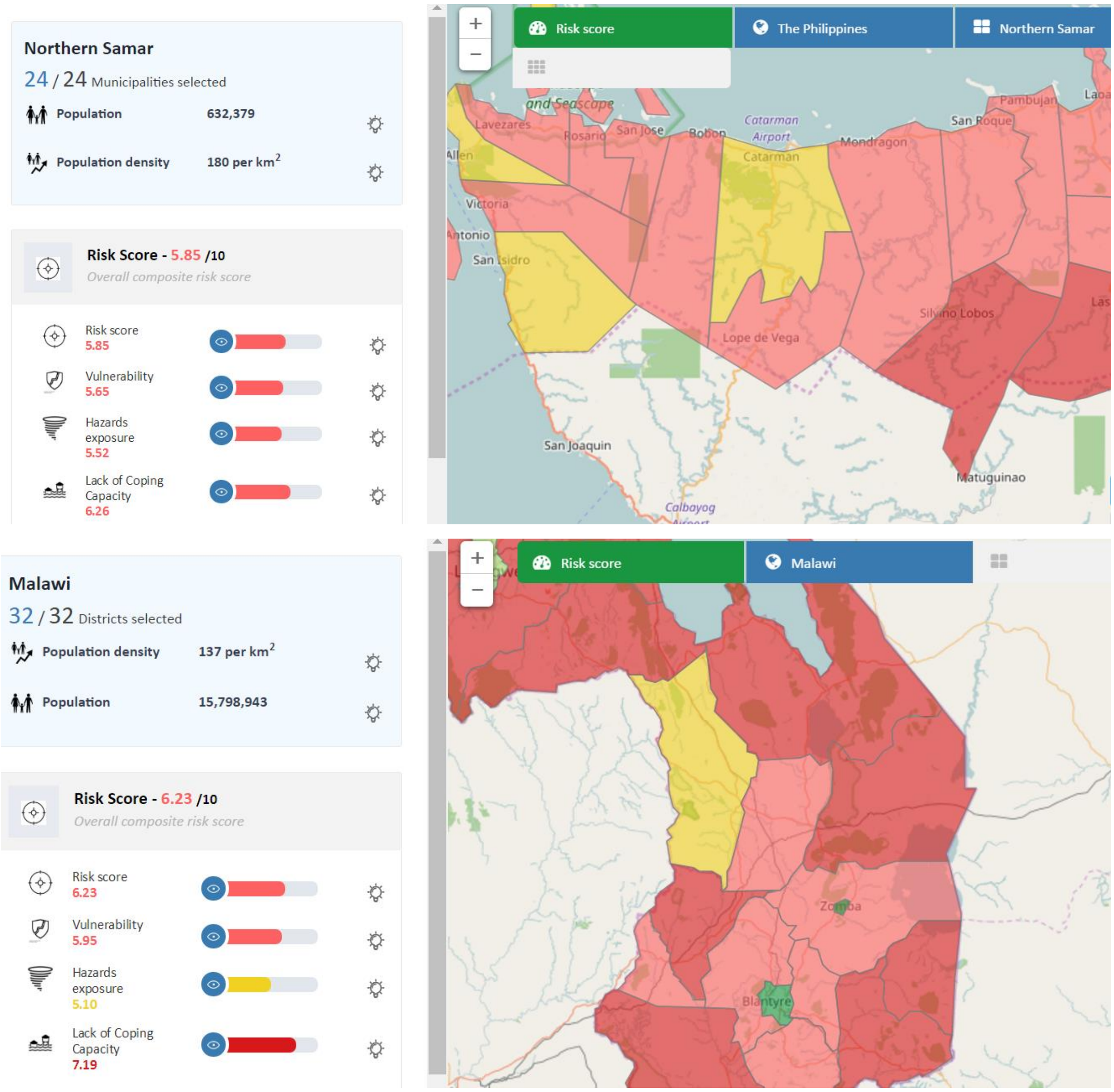

Figure 2 Community Risk Assessment dashboard for The Philippines (top) and Malawi (bottom), showing that the lower level of Data Preparedness in Malawi only allows a visualization up to the district level, whereas in The Philippines it is possible up to the municipality level.

DISCUSSIONS AND CONCLUSIONS

Data Preparedness Framework

This paper proposed a framework to assess Data Preparedness on five dimensions: Data Sets, Data Services and Tooling, Data Governance, Data Literacy, and Networked Organizations for Data. Whereas this framework is tailored to humanitarian aid, the description of the five components across the spectrum from preparedness to response also allows application in the development context. We have used this framework for the first time during a Data Preparedness Mission, where a team goes into a country, works with all the local stakeholders intensively and plugs all collected data sets into a dashboard. Possibly, data preparedness could become part of more generic preparedness missions, such as the ones that the United Nations Disaster Assessment and Coordination (UNDAC) teams execute (UNDAC, 2013; UNDAC 2017). Quantifying the different data preparedness components makes it easier to characterize the current state, to define the desired state and to focus data preparedness activities. We showed for one dimension, i.e. Data Sets, how it can be quantified.

Data Sets

First, we explained how one can use a risk indicator framework to determine which data to collect and collate. We developed a dashboard to bring all the data together in an accessible and insightful way. Red Cross National Societies can play a pivotal role around the communication and engagement with communities in relation to the dashboard. However, Red Cross National Societies are not considered apt to be the host of the data and to fulfill an administrator type of role for the such a data platform. This should be the local/national government. Subsequently, and this is the main contribution of this paper, we designed a prototype DSPI with as objectives to give direction to data collection, to track progress, to create more efficiency in the data collection and sharing and to define when it becomes possible to use the Severity and Priority tooling. The DSPI can still be extended to include other data quality dimensions. For example, Data Accessibility could be added as a factor to the equation. We saw in Malawi that especially at the lower administrative levels data could be available but not at all easily accessible. The data was not yet uploaded to geospatial sharing platforms, but kept on individual computers. Reasons for this could vary from low priority, lack of time and infrastructure (poor internet for example) to do so. The Post2015 Data Set initiative (Post2015, 2014) mentions several other subcomponents for Accessibility and clarity.

Limitations and future applications

Our research has until now solicited only limited user feedback on the DSPI. We will extend the number of case studies and application areas. 510 has advanced discussions going on with INFORM to see how the DSPI in combination with the Community Risk Assessment and Prioritization toolbox can be linked to the roll-out of the INFORM Sub-National Models. It will also be important to see how the DSPI can be linked to INFORM's reliability score. This score is a measure of reliability for each country. It is represented on a scale from 0-10 and includes missing data, out of date data, and conflict status. Countries with lower Reliability Index scores have risk scores that are based on more reliable data (INFORM, 2016).

DSPI gives direction to data collection but does not solve the issue of a lack of data at grassroots level. Alkire and Samman (Alkire and Samman, 2014) have developed ten technical criteria to evaluate different data collection methods at the household level specifically for monitoring on the SDGs. The DSPI data quality components are part of these ten criteria and can be used to assess different data collection methods. For example, social media data might score very high on Recency but the Completeness might be low if only a small percentage of the people in the area of interest use social media. We have also started mapping data providers on the indicators, since this will give an intuitive and visual representation of the data ecosystem. Such an institutional map can uncover if there are too many data providers for a certain indicator or rather too little and can subsequently be used in a data collaborative to align data collection among different organizations.

In conclusion, we developed a DSPI that can be used to monitor progress of countries on making sure they get more accurate, detailed, timely data on communities paving the way for more transparent humanitarian decision making and more inclusive reporting on global development agreements.

ACKNOWLEDGMENTS

We would like to thank Andrew Thow from OCHA and Luca Vernaccini from the EU Joint Research Center for providing us their valuable insights on the subnational INFORM index. We are grateful as well for the humanitarian decision-makers in the Philippines and Malawi who took the time for a semi-structured interview with us and more specifically the Philippines and Malawi Red Cross for hosting and supporting our mission. The Prevent a Disaster crowdfunding campaign of the Prinses Margriet Fund supported this work financially.

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Analytical Modeling and Simulation

Uncertainty Handling during Nuclear Accidents

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ABSTRACT

In the years following Chernobyl, many reports and projects reflected on how to improve emergency management processes in dealing with an accidental offsite release of radiation at a nuclear facility. A common observation was the need to address the inevitable uncertainties. Various suggestions were made and some of these were researched in some depth. The Fukushima Daiichi Disaster has led to further reflections. However, many of the uncertainties inherent in responding to a threatened or actual release remain unaddressed in the analyses and model runs that are conducted to support the emergency managers in their decision making. They are often left to factor in allowances for the uncertainty through informal discussion and unsupported judgement, and the full range of sources of uncertainty may not be addressed. In this paper, we summarise the issues and report on a project which has investigated the handling of uncertainty in the UK's national crisis cell. We suggest the R&D programmes needed to provide emergency managers with better guidance on uncertainty and how it may affect the consequences of taking different countermeasures.

Keywords

Deep uncertainty, displaying spatial uncertainty, nuclear emergency management, scenario-focused analysis.

INTRODUCTION

Emergencies inevitably involve significant uncertainties, and threatened or actual offsite releases of radiation from nuclear facilities are no exceptions. In the initial threat or early release phase the source term, its strength, time profile and composition are hugely uncertain. How the released radionuclides will be transported by winds and washed out by rain depends on the current weather and that too can be very uncertain. The uncertainty on weather and uncertainty on release content and duration also need to be treated in combination in consideration of the range of possible outcomes as they are not independent. Thus in deciding between countermeasures such as advising on the uptake of stable iodine, sheltering and evacuation, emergency managers need to be aware of and take account of these uncertainties. This has long been realised and was given some prominence in the post-Chernobyl period during which emergency management processes were reviewed and revised, a number of decision support systems were designed (French 1997, 1997, French et al. 1998). Theoretical frameworks were developed which used probability to represent the uncertainties and updated these as data became available through the use of Bayesian statistics (Caminada et al. 2000), but to date these have not been fully implemented in many systems such as RODOS (Raskob et al. 2010) and ARGOS (Hoe et al. 2002). Some of the reasons for this relate to the computational tractability of the methods and the timely availability of data; but the major obstacle is that some of the uncertainties are *deep*. Deep uncertainty may be defined in many ways (French 2015). Our view is that an uncertainty is deep when the range of plausible probabilities that one might use in an analysis is so large that few issues can be resolved by a simple quantitative analysis and that the decision making will also need to be based on judgements relating to the significance of the uncertainties. But this is not to say that the judgemental processes cannot and should not be supported by relevant quantitative analyses. To leave the process to informal discussion and intuition is to risk unsound, biased and ill-considered choices (French et al. 2009, Argyris and French 2016).

Twenty five years on from the Chernobyl Accident, the Fukushima Daiichi Disaster in 2011 has given impetus to further consideration of nuclear emergency management processes. We believe that we can no longer avoid formal approaches to the consideration of uncertainty though, as we shall argue, these may not be fully quantitative. They will, however, need to challenge and catalyse the thinking of the emergency managers so that they consider fully the possibilities given the range of the uncertainties. We shall look to the developing field of scenario-focused decision analysis to provide the structures for this. Several authors have already noted the potential of this approach to structure analyses for nuclear emergency management (Carter and French 2003, Haywood 2010, Comes et al. 2013, Comes et al. 2015).

Below we report on an exercise-based project in the UK designed to investigate the handling of uncertainty, particularly *spatial* or *geographical* uncertainty. Its results emphasise further the need for better approaches conveying the inherent uncertainties to decision makers and, indeed, scientific experts from different domains in the early stages of a radiation accident. In the next section, we describe the sources of uncertainty that arise in the threat and release phases of an accident. We then briefly describe the exercises which investigated current approaches. Reflecting on the results, we develop a scenario-focused approach to presenting the uncertainty. We also reflect on the limits of quantification, and hence modelling and simulation, during the early phase. We close with a discussion of future directions for research. Fuller details of our work may be found in French et al. (2016).

UNCERTAINTIES ABOUT THE SPREAD OF CONTAMINATION AND ITS IMPACTS

Here we limit ourselves to atmospheric transportation of radioactive contamination. Hydrological transport is also important, as the Fukushima Disaster showed, and adds to the complexity of the issues that we are addressing, but for this paper we ignore those. There are many factors contributing to the uncertainty in the predictions of the atmospheric dispersion of the radionuclides (French 2002, Haywood et al. 2010, Havskov Sørensen et al. 2014). Figure 1 and Figure 2 indicate some of these and how they influence the final uncertainty in the plume and the ultimate health impacts. Note that these figures simply represent how uncertainties and errors enter the modelling and then propagate through the modelling chain. They are conceptual and should not be read in a chronological manner from left to right. The modelling itself is iterative and complexly so. For example: there are the temporal iterations necessary to make predictions of the effects at a sequence of times to show their spread; there are computational iterations needed to ‘solve’ the mathematics; and there are iterations in the Monte Carlo simulations used in some of the modules along the model chain.

Imagine then that a reactor has ‘tripped’ in the sense that ‘warning lights are flashing’ and it is not working normally. In this situation, a release may be possible or may have already begun.

Uncertainties about factors that affect the physical process of atmospheric dispersion and deposition

- Will the aberrant conditions in the reactor lead to an off-site release? Or will the reactor be brought back under control?
- If there is a release, will it be into a sound containment building from which the gaseous radionuclides can be vented in a controlled way and particulate radionuclides filtered out of any release?
- If the release is uncontrolled, when will it occur?
- What will be the composition of the release in terms of radionuclides?
- How big will the release be?
- What will be the time profile of the release, including variation in its composition?
- What is the energy of the source term and its effective release height? If there is substantial wind shear, this will affect the direction that the plume takes.
- What will be the weather conditions at the time of the release and during the passage of the plume?
- What monitoring data do we have both on-site and off-site and how accurate are these?
- How much of the particulate release will be deposited at each stage of the passage of the plume? This will be affected by the ground topography and surface roughness and increased by any precipitation.

Uncertainties about factors that relate to the modelling used to forecast dispersion, deposition and consequent impacts

- What models are used to predict the source term? What are the assumptions underlying these?
- What atmospheric dispersion and deposition models are to be used? What are the assumptions

underlying these?

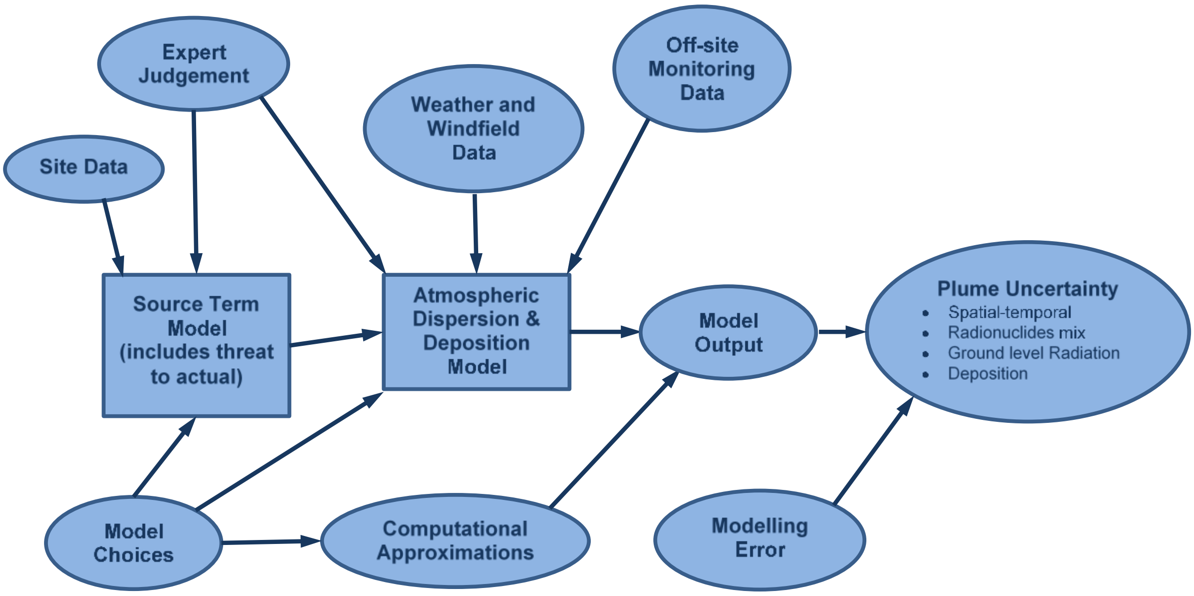

Figure 1: Factors contributing to the uncertainty in the spread of atmospheric dispersion

- What statistical analysis is used to assimilate monitoring data into the models?
- Where is expert judgement used to set model parameters or similar? How uncertain are these judgements? How well calibrated are the experts?
- What numerical methods are used to approximate the solution of the dispersion and deposition models?
- How good is our GIS data in terms of topography, geology, land use, agricultural production, position of dwellings and local populations?
- What models are used to assess potential agricultural impacts and the potential need for immediate food bans?
- How good is our knowledge of the demography, diet and behaviour in the areas potentially affected?
- What assumptions and models are used to predict any health effects?

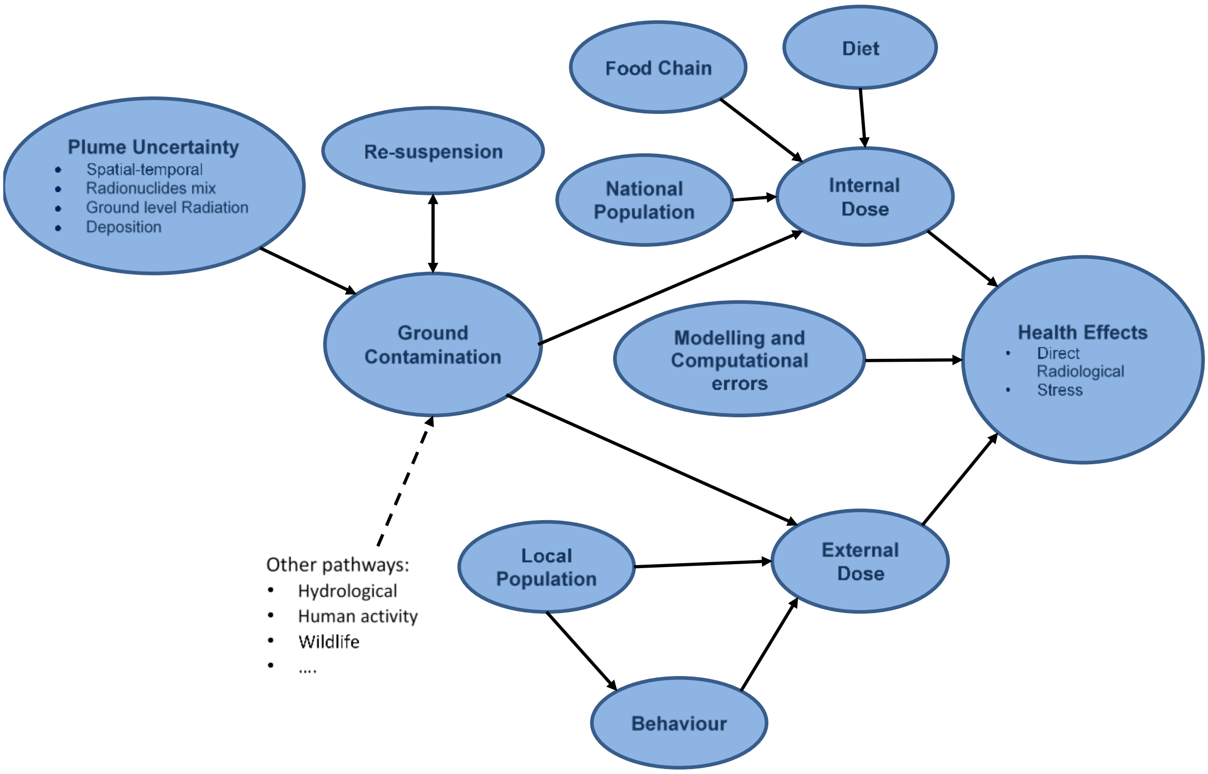

Figure 2: Factors contributing to the uncertainty in the predictions of dose and human health effects

- If several models are used in parallel to predict broadly the same effects, how are any conflicts between their predictions resolved?
- If we could calculate perfectly and had perfect data, how accurate would the models be in predicting the impacts in this situation?

In the first hours, the uncertainty in modelling public health impact assessments is generally dominated by source term uncertainties such as the release height, timing and scale and, secondly, to meteorological uncertainties, particularly the arrival of any front and precipitation patterns (Haywood et al. 2010).

The modelling of the processes that lead to health and other impacts involves much simplistic averaging across many sub-groups. Moreover, the *linear hypothesis*, which is used to estimate the health risk to populations exposed to very low levels of radiation over long time periods, is precisely what its name suggests: a hypothesis justified by linear extrapolation from observed effects at much higher doses (Argyris and French 2016, Blandford and Sagan 2016). When combined with many conservative assumptions on the average exposure of members of the population, the linear hypothesis may lead to overestimation of the public dose.

Quantifying all of these uncertainties coherently without time constraints would be a challenge. Given the urgency in the early phase of a radiation accident and given that some uncertainties, particularly those relating to the source term, are deep, the challenge is enormous.

Note also that the decision makers are interested in what action to take *where* and *when*. So many uncertainties that are of concern to them have spatial-temporal aspects and these are particularly difficult to communicate (French et al. 2016)

THE ADMLC PROJECT AND CURRENT UK PRACTICE

The work reported here was part of a project funded by the UK Atmospheric Dispersion Liaison Committee (ADMLC). The project's focus was on how information would be presented to the scientific advisors to the UK's national crisis response group. It did not consider the many similar issues which arise in the co-ordination of the local response. The project involved a range of activities, including a substantial literature review; however, its key elements related to three workshops, all using hypothetical scenarios to focus their discussions and illustrate the many uncertainties that arise in responding to a radiation accident. During each workshop an accident scenario was presented, stepping through the first few hours and explaining what would be known at each time, what would not be known, what seemed most likely to happen, and what the radiological and health impacts might be. The first workshop sought to understand the current processes of information presentation and discussion. It involved members of Government departments and agencies, who might well be involved in advising on the handling of an actual radiological emergency. Discussion focused on how to advise senior ministers and officials on the significance of the uncertainties involved in predicting the course of the plume, the impact of this on health and the likely need to prepare resources to support recovery. Building on this experience, the project developed proposals for presenting information on the potential geographical spread and impact of a radiation plume. The second workshop involved many world experts on the presentation of scientific and expert advice in high risk contexts, and aimed to challenge and criticise these proposals. The third workshop had similar attendance to the first, but this time focusing on the presentation of information using plots, graphs, and other display techniques proposed by the project to convey the uncertainty, and then to reflect on how useful the different approaches were.

At present, no or very few uncertainties are quantified in the information that the agencies, responders and plant operators provide to the advisors or emergency managers. In the discussion at the first workshop we observed that the group focused on a *reasonable worst case* (RWC). It is not an easy concept to define. Essentially, the idea is to think about how bad things might get so that appropriate resources can be put in place, which is why consideration of RWC is common in emergency planning. In that context it is defined as being designed to exclude theoretically possible scenarios which have so little probability of occurring that planning for them would lead to a disproportionate use of resources. The concept has been taken over from emergency planning into emergency response without apparent recognition that the contexts of these two activities is significantly different. The former considers the possibility, remote or otherwise, of some disaster. The latter relates to something that has most definitely happened. It is far from clear that emergency response should focus almost entirely on a single reasonable worst case. There may be many different negative impacts (health, agricultural, economic, etc.) that could arise and some may not be visible in a single RWC. Moreover, while it sounds sensible to prepare for the reasonable worst, it is important to realise that an actual event may not evolve into such a negative extreme. Framing issues so negatively has long be recognised in psychological studies as increasing risk taking in decision making (Kuhberger 1998, French et al. 2016): not a characteristic one might wish to encourage in emergency management. Also the advice and assessments to be presented to the emergency management team is sought to support decision making. It is not clear that describing a reasonable worst case is the most helpful form of information for this. The focus of a reasonable worst case is simply on what might happen. It does not offer an analysis of what might happen were different actions taken.

A way to avoid focusing on a single reasonable worst case may be to build on the ideas of scenario analysis and offer crisis managers several potential scenarios. Scenario analysis is used throughout business and government to develop strategic thinking (Schoemaker 1995, van der Heijden 1996). More closely to our context, it is used in volcanic emergency response. Currently there is a growing interest in using scenarios to tackle problems with deep uncertainty (French 2015). The most basic forms of scenario analysis develop a series of maybe 4 or 5 scenarios that are 'interesting' in some sense and may be used as backdrops for strategic conversations. How ‘interesting’ is defined is moot, with many possibilities. Perhaps:

- reasonable best and worst cases of some form – useful for bounding possibilities;
- a likely case – useful for maintaining a balanced perspective;
- an assumption that a particular event happens or does not – useful if a significant event such as structural damage to a containment building is unpredictable and shrouded in deep uncertainty.

Following on our remarks that there may be no single reasonable worst case which illustrates all potential negative impacts, this might be extended to cover two or three reasonable worst cases. Note that only a handful of scenarios are developed. Part of this is because in qualitative scenario analysis, each scenario is carefully explored and there is not time to do more; certainly not within the context of emergency management. But there is also the issue of cognitive capacity in that decision makers often cannot absorb and balance out the implications of many scenarios (Miller 1956).

In the scenario analyses undertaken within strategic management, the scenarios are developed in discussion between the decision makers and their advisors. In the context of emergency management this would be too time consuming. The scenarios need to be developed by the ‘backroom analysts’ and presented to the emergency management team. We suggest that the scenarios might be developed by focusing on the key uncertainties (Schoemaker 1993, Mahmoud et al. 2009). In our case, the key uncertainties relate to:

- the source term including release profile, release composition, and release height;
- weather including windfield, precipitation, and the arrival of any sudden changes such as that caused by a front.

Figure 3: Generating scenarios to consider during a radiation accident
BC – best case; LC – likely case; RWC – reasonable worst case; WC – worst case

The first step is to discretise the possibilities: see Figure 3. The tree on the left suggests how different possible weather systems might be generated: will or will not a front arrive; how might the windfield evolve; will or will it not rain? Obviously, one might consider not whether a front will arrive, but at what time it will arrive, generating more than two possibilities. Other eventualities may be split into more or less possibilities. What matters is that developing such a tree helps set up a set of different weather systems that are candidates for consideration in the analysis. Similarly, the possibilities for the source term (the tree at the top of the figure) are partitioned according to its time profile, its composition and its effective release height. However, we do emphasise that this is indicative at least conceptually of how the various possibilities might be developed. The leaf nodes of the weather and source term trees label the rows and columns. Each element in the table defines a scenario. Even with the simplest set of possibilities on the components of the source term and weather, there would be too many scenarios to generate, much less discuss with the advisors and emergency managers. Thus we suggest that judgement is used to select 4 or 5 scenarios which span the range of possibilities to help those making the decisions appreciate the range of possible impacts. But note that these 4 or 5 scenarios are not meant to form a partition of the future. Figure 3 contains many unsampled possibilities. Thus the scenarios cannot be connected by a decision tree or similar model.

That the presentation of each scenario would include maps or sequences of maps showing the evolution of events under the assumptions implicit in its definition. Figure 4 gives an example of dose bands integrated over 2 days. Note that much simulation and modelling are used to develop each scenario. Indeed, uncertainty calculations may be made within a scenario, e.g. in generating meteorological ensembles. Our approach quantifies *within* scenarios, but leaves comparisons *between* scenarios unquantified (Stewart et al, 2013, French, 2015). Since the assignment of probabilities given the paucity of data and the urgency, the key idea in presenting several scenarios is to stretch the emergency management team's thinking and make them consider a wide range of possibilities. It should also encourage them to recognise variation and that impacts will differ in reality from the models, leading to greater flexibility in their response. We also note that presenting scenarios via maps as in Figure 4, helps in appreciating some of the spatial temporal uncertainty.

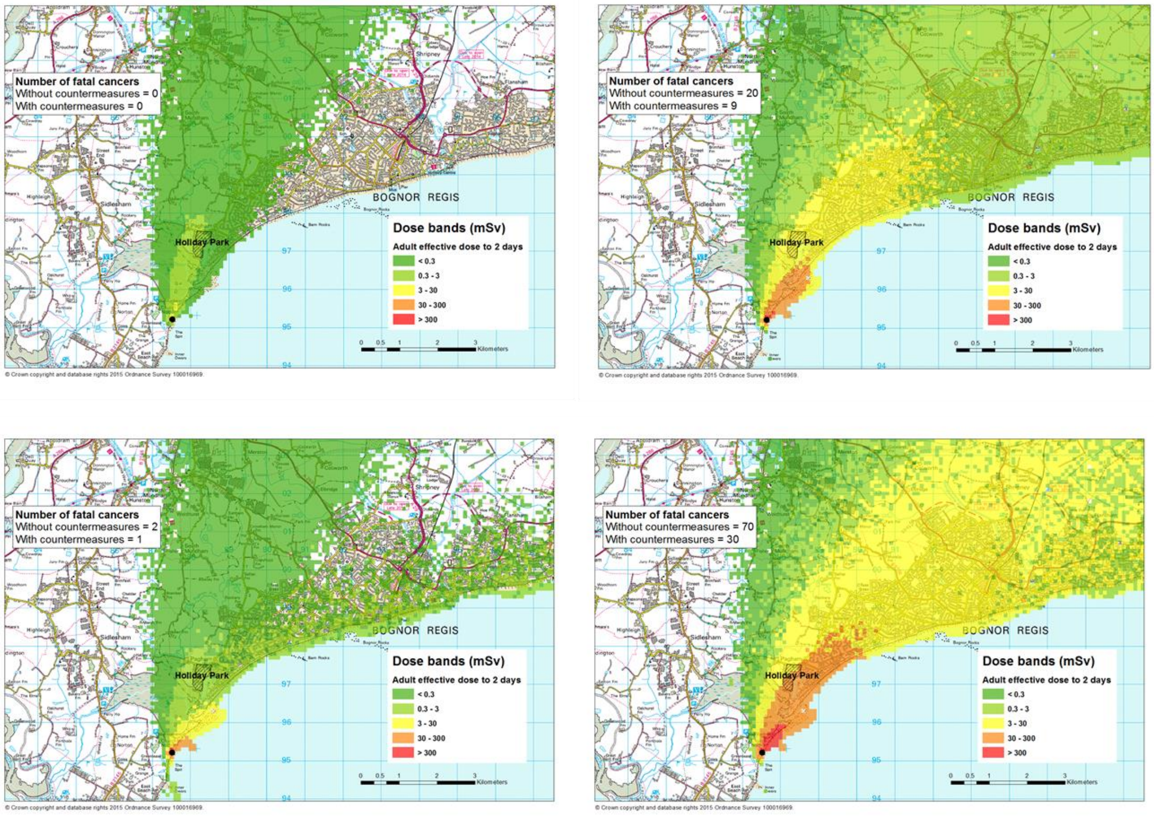

Figure 4: Plots of dose bands from four scenarios used in the exercise
Note 1: These are entirely hypothetical scenarios based on a hypothetical site.
Note 2: The plots are not probability distributions, but rather are predicted dose given the different scenarios' assumptions on source term and meteorology.

The project discussed this proposal at the second of its workshops and then ran an exercise in the third workshop with the same range of participants from across government and its agencies as the first. We created a hypothetical accident in which there was a possibility that a small early release might be capped, but if not it could develop into a second very significant release. The meteorology included the arrival of a front with an associated change of wind direction which could take the plume out to sea, so the timing of any second release was important, but very uncertain. If it went over land, the plume could reach a sizeable town and also would have considerable agricultural impact with extensive food bans. Our team developed several scenarios with different combinations of source terms, release times and meteorology. Recognising that only a handful could be presented to the emergency managers in a reasonable time, we selected four to present at the exercise, which spanned the possibilities.

The exercise was not an unqualified success. Presenting the scenarios did open up the discussion, but the participants relatively quickly chose one as a RWC and concentrated on that. Moreover they really only considered immediate health concerns and ignored, for example, potential agricultural issues. They did discuss uncertainty more than in the first workshop, considering the probability of a significant second release. However, there was a confusion between the unconditional probability of a very significant second release and its conditional probability *if* a second release occurred, the former being much smaller than the latter. This meant that their discussion was based on much higher chance of serious impacts than the evidence presented to them was meant to suggest. This observation emphasises that experts are as prone to error as anyone else (Kahneman and Klein, 2009; French et al, 2016), and that procedures to ensure continual challenge and hence reflection and checking of their thinking should be adopted in their discussions.

DISCUSSION AND NEXT STEPS

The lack of full discussion of the range of scenarios in the context of this exercise is disappointing, but has not discouraged us. We are, if ever, more convinced of the need to develop current emergency management practices to recognise the issue of uncertainty explicitly in their deliberations and decision making. We ran a fourth exercise followed by a discussion with scientists and researchers attending *Radiation Protection Week* held in Oxford in September 2016. They too agreed with our conclusion that too little attention is paid to uncertainty in current practices and this needs to be addressed.

There are simple things we might do that could make emergency management teams consider more carefully a range of scenarios. Most simply we could have prepared tabulations and graphical displays that compared the different potential impacts of the scenarios. Our presentations stepped through the four scenarios a little too separately and might well have compared across them rather more. Another tactic would be to develop key points for a press release. In previous work (Bennett et al. 1999, Bennett et al. 2010), it was noted that focusing on what to tell the public would widen the discussion so that the public were prepared for different possibilities, while still reassuring them that the authorities were taking appropriate steps to mitigate the potential outcomes. In this context, we would be concerned that the focus on immediate health issues could lead to ministerial statements which ignored other significant issues such as potential food bans and agricultural impacts. Failing to forewarn the public about the potential scale of these could lead, if they were needed, to subsequent increases in stress levels with the concomitant health impacts that have been found after Chernobyl and Fukushima (Havenaar et al. 2003, IAEA 2006, 2015). Thus we would consider catalysing wider discussion in a future exercise by asking for 'bullet-points for a press release'.

A more significant development would be to bring an explicit discussion of probabilities into the process. But this is non-trivial. Firstly, as we have noted some aspects of the accident may be deeply uncertain; secondly, even when the deep uncertainties have been resolved – or sidestepped by fixing deeply uncertain entities within a scenario – there may be insufficient data or computational time to conduct an adequate probabilistic analysis. Nonetheless, after the first few hours as the cause and likely progress of the release becomes clearer, it may be possible to use expert judgement to assess rough probabilities. Even if this is not possible in a real accident, exploring such ideas in training exercises may help emergency managers develop an awareness of the value in deliberating on the uncertainties and the full implications of *not* considering these.

So consider Figure 3 further. Note that the five scenarios clearly only allocate a small fraction of the probability mass: i.e. it is much more probable that something else will happen. If probabilities are to be used sensibly we need to look at all possible scenarios. What we might do is ask the advisors with suitable expertise to assign rough probabilities to broad events whose outcomes are similar to the five modelled scenarios. By 'outcome', we mean the health, agricultural and other consequences that arise from the contamination. By 'similar to' we mean the overall impact of these consequences is roughly the same. Thus we might ask the advisors to discuss the likelihood of four events (see Figure 5):

- *Event 1*: the outcome is broadly similar to that shown in the BC scenario, though the details including the precise geographical area affected may be different (shaded yellow).
- *Event 2*: the outcome is broadly similar to that shown in the LC scenario, though the details including the precise geographical area affected may be different (shaded green).
- *Event 3*: the outcome is broadly similar to those shown in the RWC1 and RWC2 scenarios, though the details including the precise geographical area affected may be different (shaded blue).
- *Event 4*: the outcome is broadly similar to that shown in the WC scenario, though the details including the precise geographical area affected may be different (shaded red).

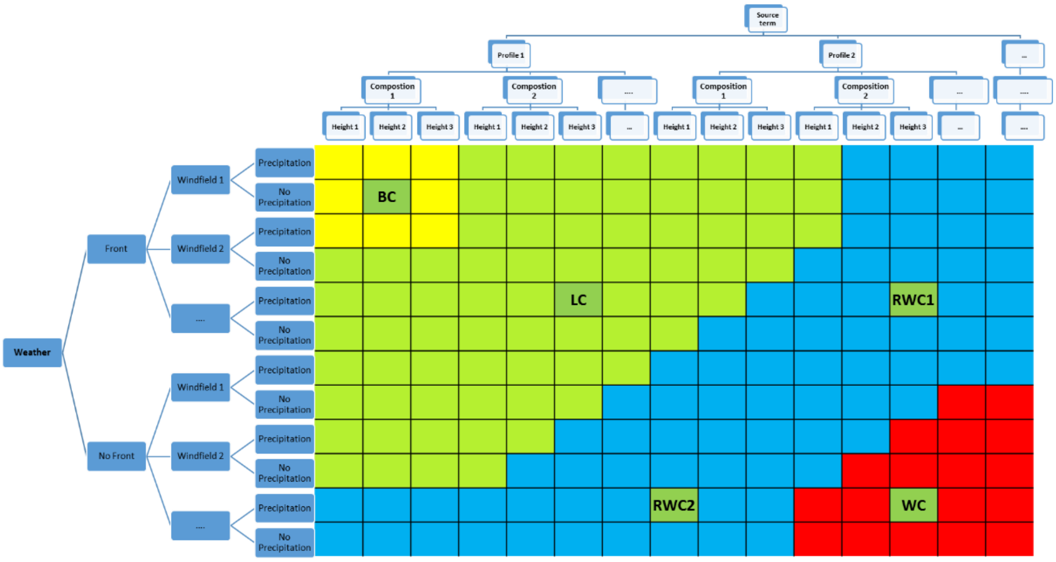

Figure 5: Possible way of reintroducing probabilities into the analysis

In simpler terms, in deliberating on the possible decisions to be taken we would ask the advisors to summarise the uncertainty in the form:

> "At the moment our informed judgement is that there is a probability of *a*% that the outcome could be as good or better than BC, a probability of *b*% that the outcome will be comparable with LC, a probability of *c*% that it could get as bad as RWC1 and RWC1 or something similar, and a probability of *d*% that it would get as bad as WC."

Clearly $a+b+c+d = 1$ in this case; and by the time that deep uncertainties have become resolved, one would expect $(c+d)$ to be very much less than $(a+b)$.

We hope to explore these ideas in future exercises. To be honest, we wonder whether the description of events 1 to 4 are too complex for experts to comprehend and thus assess probabilities, however approximately. However, we are convinced that more attention need be paid to the inherent uncertainties and to all the potential impacts in the early phase and that emergency managers need to be sensitized to such issues.

ACKNOWLEDGEMENTS

Our recent work has been funded by the UK Engineering and Physical Sciences Research Council under grant reference number EP/K007580/1 and by the UK Atmospheric Dispersion Modelling Liaison Committee, as well as by the organisations in which we work. Before that we have worked on many UK and European research and development projects relating to crisis management. We have had many useful discussions with colleagues on these projects and more generally across the community of emergency managers. We are grateful to all for their thoughts and input. However, we would emphasise that the views expressed here are ours and are not necessarily held by any of our funders or colleagues.

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Evaluation of Conversion to Quake-Resistant Buildings in Terms of Wide-Area Evacuation and Fire-Brigade Accessibility

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ABSTRACT

It is important to evaluate the effects of improving the disaster vulnerability of towns by using various indices related to human damage. In this paper, we focus on conversion of low quake-resistant old buildings. Firstly, we construct a simulation model, which describes property damage (such as building-collapse and street-blockage), wide-area evacuation behavior, and fire-brigade's activities immediately after a large earthquake occurs. Next, using the simulation model, we estimate the travel time required for evacuation, the number of evacuees trapped on streets (or in blocks), and the access time of fire-brigades to fires in case that the ratio of quake-resistant buildings in the area increases to a certain value. Based on the results, we discuss the effects by converting old buildings into quake-resistant ones on reducing the difficulty in wide-area evacuation and improving the accessibility of fire-brigades in multiple study areas with different characteristics.

Keywords

Conversion, quake-resistant building, property damage, wide-area evacuation, fire-brigade.

INTRODUCTION

In order to strengthen the resilience of densely populated residential areas to natural disasters, it is necessary to visually and quantitatively grasp the potential of property/human damage caused by disasters, to draw up a concrete plan for reducing the risk of such damages, and to encourage the reconstruction/demolition of vulnerable buildings based on disaster prevention/mitigation planning. In some cases, municipalities or residential developers provide a grant for residents to accelerate the redevelopment project, but in many cases, residents have to pay almost all the money for reconstruction by themselves. To motivate them and promote the improvement of the urban vulnerability to disasters, it is important not only to provide more grant for more residents but also to sufficiently consider the effects on enhancing local disaster prevention/mitigation performance by reconstructing/demolishing each vulnerable building on the basis of quantitative analyses from the various viewpoints (such as economic loss, number of damaged buildings, number of human casualties, etc.).

In Japan, it has been said that major earthquakes equivalent to the Great Hanshin-Awaji Earthquake in 1995 (magnitude 7.3) will occur near multiple large cities (including Tokyo Metropolitan Area) with a probability of 70% in 30 years (Cabinet Office, Government of Japan, 2015; Headquarters for Earthquake Research Promotion, 2017). In these cities, there are many densely built-up wooden residential areas, which consist of many wooden houses and narrow street networks, with high risk of devastating property damage (such as building-collapse, street-blockage by rubbles of collapsed buildings, and fire-spread) and human damage at the time of a large earthquake. Therefore, it is highly necessary to convert wooden houses with insufficient quake-/fire-resistant performance into quake-/fire-resistant buildings (such as reinforced concrete structure, steel-frame structure, etc.).

There are some previous studies that focus on conversion of building structures or materials to an incombustible state. For instance, Osaragi (2004) proposed a statistical model that can evaluate characteristics of buildings and location, which affect the life span of buildings. Also, a model for evaluating the speed of conversion to an incombustible-city state was developed, and simulations of conversion of buildings for 30 years were executed by using actual data taken from the densely built-up areas (Osaragi, 2005). On the basis of the simulation results, the author suggested that effective planning (e.g., providing subsidies) was necessary for promoting conversion of buildings structures into an incombustible state. Furthermore, the effect and efficiency on promoting the incombustibility of residential areas by applying some urban regulations (such as changing building-use regulation designated in each area, increasing floor-area ratio of buildings, etc.) were evaluated by simulating the time-series changes of building structure (Osaragi, 2013). The proposed models of conversion of buildings in urban areas are detailed, therefore, the results in these studies are meaningful for understanding the mechanism of conversion of buildings and for considering disaster prevention/mitigation planning. However, the impact of the conversion on human activities such as wide-area evacuation and travel of emergency vehicles was not analyzed in these studies. In other words, on the basis of the simulation results in these studies, it is difficult to realize whether the specific measures regarding conversion of buildings are sufficiently effective or not for the improvement of human activities in the event of a large earthquake.

Other studies attempt to quantify the effects on reducing property or human damage due to the specific natural disaster by converting towns. For instance, Kuwasawa and Katada (2008) and Ito et al. (2015) developed the simulation models which described street-blockage by rubbles of collapsed buildings and the evacuation behavior from tsunami immediately after a large earthquake occurred. Using the models, the authors estimated the number of casualties/survivors or the time required for completing evacuation in case that the ratio of quake-resistant buildings increased. Also, Oki and Osaragi (2016) constructed the simulation model which described wide-area evacuation from fire-spread after a major earthquake occurred, and evaluated the actual project to improve buildings and streets implemented in the past based on the estimated number of people with difficulty in wide-area evacuation. Additionally, as an example of applying the simulation model to urban disaster mitigation planning, the authors demonstrated the effects of adding new evacuation routes between two intersections of streets with narrow width and long distance. These studies are suggestive for considering the relationship between the improvement of disaster vulnerability of towns and the decrease of human damage in disaster prevention/mitigation planning. However, in these studies, only few indices related to wide-area evacuation in human activities were used for evaluating the effects. Moreover, the difference of the effects among multiple areas with different urban characteristics was not sufficiently considered.

In this paper, we develop a simulation model, which accounts for property damage (such as building-collapse and street-blockage), wide-area evacuation activity, and fire-brigade's activity right after a large earthquake hits. Using the integrated simulation model, we analytically evaluate the impact of converting low quake-resistant old buildings to quake-resistant ones in terms not only of wide-area evacuation but also of fire-brigade accessibility. More specifically, we estimate the travel time required for evacuation, the number of evacuees trapped on streets (or in city blocks), and the access time of fire-brigades to fire origins. Additionally, in order to understand the relationship between urban characteristics and effects of converting low quake-resistant buildings, the simulations are executed under the assumption of different ratios of quake-resistant buildings in multiple study areas with a different degree of the vulnerability to earthquake.

Hereafter, a "quake-resistant building" indicates the one built in 1981 or later based on the new building codes, which prescribe that a new building must be constructed with the quake-resistant performance so as to prevent it from the collapse even by an earthquake of rare severity. In the 1995 Great Hanshin-Awaji Earthquake, the ratio of collapsed buildings was much less in the buildings based on the new building codes than in the others (Murao and Yamazaki, 2000).

OVERVIEW OF SIMULATION MODEL

Figure 1 indicates the overview of analytical procedure in this paper. Firstly, we mention how to estimate the structure and built year for each building. Next, the models which describe the conversion to a quake-resistant building, property damage (i.e., building-collapse and street-blockage), wide-area evacuation behavior, and the activities of fire-brigade are shown. Subsequently, we implement the simulations of wide-area evacuation and fire-brigade activity separately, and attempt to quantify the effects of conversion to quake-resistant buildings in terms of these activities.

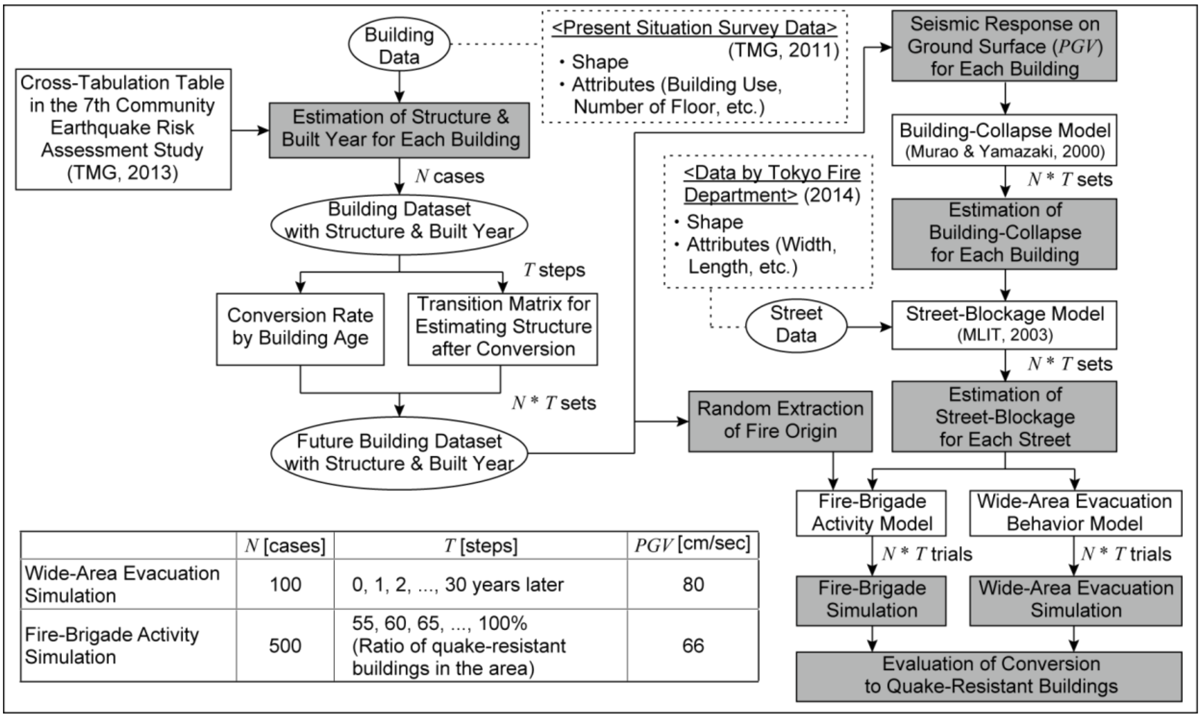


Figure 1. Overview of Analytical Procedure in This Paper

Building Data

We used the building dataset based on the present situation survey on land/building use in 2011 published by Tokyo Metropolitan Government. This dataset includes the GIS data on all the buildings in Tokyo (approximately 2.8 million buildings), and we can obtain the information on shape and attributes (such as building use, number of floor, fireproof performance, *chome* [traditional Japanese address unit], etc.) of buildings. However, there are no information on the structure (wooden / reinforced concrete / steel) and built year of each building, which are necessary for building-collapse simulation. Therefore, we estimated them by using not only the present situation survey data in 2011 but also the 7th Community Earthquake Risk Assessment Study (TMG, 2013) according to the following procedure:

(1) Structure: (a) The buildings, which were categorized as “naked-wooden building” or “fireproof building” in the present situation survey data, were determined as “wooden” buildings; (b) The composition ratio of buildings was calculated by the cross-tabulation of three variables (*chome* / number of floors [1 to 3 / 4 to 7 / 8 or more] / structure) according to the 7th Community Earthquake Risk Assessment Study; (c) Each semi-fire-resistant building was probabilistically categorized as “wooden”, “reinforced concrete”, or “steel” according to the composition ratio mentioned in (b); (d) Similarly, each fire-resistant building was probabilistically categorized as “reinforced concrete” or “steel”.

(2) Built year: We calculated the composition ratio by the cross-tabulation of five variables (*chome* / fireproof performance / number of floors / structure / built year) according to the 7th Community Earthquake Risk Assessment Study, and estimated the built year range [1970 and before / 1971 to 1980 / 1981 to 1990 / 1991 to 2000 / 2001 and later] of each building as well as the structure.

Conversion to Quake-Resistant Building

Firstly, we estimated the trend of conversion to quake-resistant buildings. More concretely, we estimated the ratio of conversion by building age (elapsed year since a building was built) and the transition matrix for estimating structure after conversion based on the present situation observation data (as of 2001 and 2006) for land/building use in Setagaya Ward, Tokyo. Comparing the data for two different year (2001 and 2006) from the viewpoint of both the shape and the attribute of building, we determined whether each building had been converted in five years. Figure 2 shows the relationship between the ratio of conversion and building age. We considered that the ratio of conversion was independent of building’s structure because of estimation stability.

The graph indicates that the ratio of conversion increases by 0.05% every year since a building was built. Additionally, we constructed the transition matrix for estimating structure after conversion (Table 1). The matrix was estimated by using the cases where the structure of building before/after conversion could be known.

In the simulation, we prepared the data on conversion to quake-resistant buildings for each year/case as follows: (1) Estimating probabilistically whether each building is converted or not in the specific year based on the ratio of conversion by building age (Figure 2); (2) Estimating the structure after conversion for each building by using the transition matrix (Table 1).

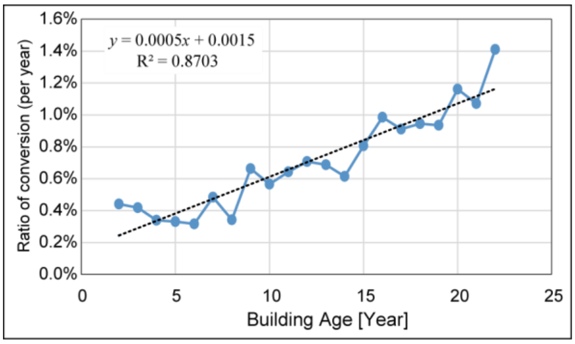


Figure 2. Ratio of Conversion by Building Age

Table 1. Transition Matrix for Estimating Structure after Conversion

Before / After [%]	**W**	**RC**	**S**	**Total**
Wooden	67.8	15.7	16.5	100
Reinforced Concrete	36.0	51.7	12.4	100
Steel	39.8	34.9	25.4	100
Total	56.4	24.7	18.9	100

Building-Collapse and Street-Blockage

The property damage models, which consist of the building-collapse model and the street-blockage model, were constructed with reference to Hirokawa and Osaragi (2016).

Peak Ground Velocity (PGV) is one of the input data to the building-collapse simulation. The velocity for buildings in each grid (50m square / 250m square) can be estimated by using the surface-ground response model considering both the decay effect by distance from the earthquake center and the amplification effect by characteristics of subsurface ground. However, in this paper, we fixed the PGV to a certain value (66 cm/sec or 80 cm/sec) in the whole study area in order to clarify the influence of composition of buildings and streets excluding the surface-ground response.

For estimating whether each building completely collapsed or not, we used the collapse probability model according to the building's structural material (wooden / RC / steel) and built year. The model was originally proposed by Murao and Yamazaki (2000) based on the survey report of building damage by the Hyogo-ken Nambu Earthquake (or the Great Hanshin-Awaji Earthquake) in 1995, and later improved by adding the data in Niigata-ken Chuetsu-oki Earthquake in 2007 (TMG, 2013).

$$P_R\left(PGV\right) = \Phi\left(\frac{\ln\left(PGV\right) - \lambda}{\xi}\right)$$

Here, λ and ξ are the average and standard deviation of $\ln(x)$, respectively; they vary according to the structural material, built year, and degree of damage. $\Phi(x)$ indicates the cumulative function of standard normal distribution, and $P_R(x)$ is the probability that a building is completely destroyed by an earthquake over a certain level ($x = PGV$). We estimated building-collapses based on uniform random numbers and the collapse probability.

Based on the result of building-collapse estimation, we determined whether each street was blocked or not, by using the street-blockage model proposed by MLIT (2003). In this model, the probability $f_i(W)$ that a street-blockage would occur as the result of collapse of a single building i along the street with a width of W [m] (considering the average setback distance) is expressed as follows:

$$f_i\left(W\right) = D_C\left(1.1753A - 0.0514\right) \times \exp\left(\frac{-W}{2.58P_{area}^{0.379} + 0.210F^{2.23} + 4.90A^{12}}\right)$$

Here, D_C is the building condition (1: collapsed, 0: not collapsed); A is the building coverage ratio; P_{area} is the average ratio of completely collapsed buildings in the block where the building is located; F is the number of floors; and G is the group of buildings along the street. Therefore, the probability $P_b(W)$ that a street-blockage would occur can be formulated as follows:

$$P_b(W) = 1 - \prod_{i \in G} \left(1 - f_i(W)\right)$$

The minimum passable width, which was calculated on the basis of $P_b(W)$, was set to: 3 m for fire engines; 1 m for evacuees; and 0 m for firefighters.

Wide-Area Evacuation Behavior (Figure 3(c))

We assumed the rule of evacuation behavior as follows:

Start evacuation: People inside buildings start evacuating (travelling) as the time has elapsed after an earthquake occurs base on Poisson distribution (Figure 3(a)). By contrast, pedestrians start evacuating (travelling) immediately after an earthquake occurs.

Destination of evacuation: It is considered that evacuees can travel to an evacuation area more safely when they pass through wide streets as long as possible. Such wide streets have a low possibility of blockage by rubbles of collapsed buildings and work as firebreak belts. Therefore, in this paper, we assumed that people travel to national/prefectural roads with a width of 8 m or more, and considered that they complete evacuating when arriving at any of intersections on the roads.

Route choice: Evacuees select the route to their own destination so that the total value of L/W (length divided by width for each street-link) is minimized in order to enhance a possibility of using wide streets.

Street-blockage and evacuation behavior: Firstly, evacuees do not have any information on the number and spatial distribution of street-blockage. They memorize the situation of blockage on the street connected to the intersection they passed. When an evacuee encounter a street-blockage and cannot use the evacuation route, he/she searches another evacuation route considering the situation of street-blockage in the whole area that he/she has already grasped. At the same time, the number of street-blockage that he/she encounters is updated. If an evacuee cannot reach any intersections on all the target streets (national/prefectural roads with a width of 8 m or more) due to street-blockage, he/she is considered as “a person with difficulty in wide-area evacuation (a person trapped on a street / in a block)”.

Walking speed: It is considered to be a function of evacuees’ density (Figure 3(b)) on each street-link (not faster than 4 km/h).

The location of each evacuee at an earthquake occurrence time is set in a building or on a street intersection, which is, for instance, estimated based on the data of the person-trip survey referring to the method proposed by Osaragi and Hoshino (2012).

Activity of Fire-Brigade (Figure 3(c))

When a fire-brigade leaves a fire station, it firstly travels to any water source by a fire engine. After arriving at a water source, firefighters get off the fire engine and run to the fire origin (building). Namely, we estimated the time required for travelling from a fire station to a fire origin. Here, the cases where a fire-brigade could not reach a fire origin due to street-blockage were excluded in the calculation of the travel time.

All fire-hydrants were assumed to be unavailable because the water supply was cut off due to earthquake. Also, we assumed that a fire-brigade moved toward the water source (excluding fire-hydrants) so that the expected travel time, which was defined as the sum of T_1 (the time distance from the current location of the fire-engine to a water source) and T_2 (the Euclidean distance from a water source to a fire origin divided by 167 [m/minute]), could be minimized.

The influence on the activity of fire-brigades by street-blockage was considered to be basically same as the case of evacuees. The difference was that fire-brigades were assumed to spend 30 seconds for restarting the travel after encountering a street-blockage. The travel speed was assumed as shown in Table 2.

Table 2. Travel Speed

Attribute	Travel Speed
Firefighter	167 [m/minute] (= 10 km/h)
Fire-engine on urgent transportation road	Speed limit of the road
Fire-engine on street with a width of more than 6 m	0.8 times of speed limit of the road
Fire-engine on street with a width of 6 m or less	0.5 times of speed limit of the road

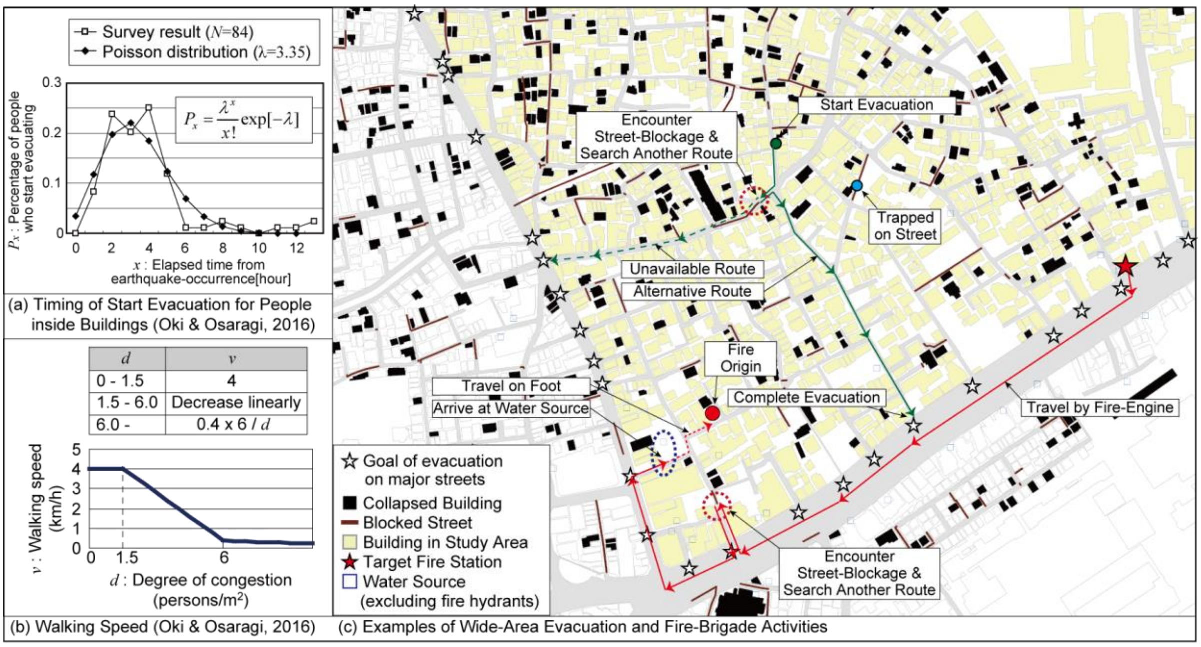


Figure 3. Wide-Area Evacuation Behavior and Fire-Brigade Activity

EVALUATION OF CONVERSION TO QUAKE-RESISTANT BUILDINGS IN TERMS OF WIDE-AREA EVACUATION

Study Area and Assumptions in Simulation

We extracted multiple study areas from densely built-up wooden residential areas in Tokyo (Table 3). Many national/prefectural roads form a mesh, and all of the study areas are surrounded by such major roads with a wide width. Sumida A, Sumida B, and Arakawa are located in the eastern part of Tokyo 23 Wards. According to the 7th Community Earthquake Risk Assessment Study (TMG, 2013), these areas have high risk of building-collapse in a large earthquake (Figure 4, upper left-hand panel). Also, most streets inside each study area are extremely narrow (Figure 4). By contrast, Suginami and Shinagawa are located in the western part and southern part of Tokyo 23 Wards, respectively. Although the width of streets inside each study area is narrow as well as the other areas, the risk of building-collapse in a large earthquake is comparatively low (Figure 4).

In the simulation, the evacuees are considered to succeed in evacuating when they arrive at any of intersections (indicated by star in Figure 4) on major roads. The numbers of buildings, street-link, and people in each study area are shown in Table 3. We prepared 100 cases of property damage (building-collapse and street-blockage) estimated by the property damage model, and carried out one trial for each case.

Table 3. Profile of Study Areas (Wide-Area Evacuation)

	Sumida A	Sumida B	Arakawa	Suginami	Shinagawa	Total
Constituent *Chome*	Sumida 1 – 5 Higashi-mukoujima 4 – 5	Yahiro 1 – 5 Higashi-mukoujima 6	Arakawa 5 – 6 Higashi-ogu 1 – 3	Koenji-minami 2 – 4 Asagaya-minami 1 – 2	Nakanobu 1 – 6 Nishi-nakanobu 1 – 3 Higashi-nakanobu 1 – 2 Hatanodai 2 – 5 Kita-magome 1 – 2 Kami-ikedai 1	
Num. of Buildings	6,713	5,851	4,931	6,300	9,799	33,594
Num. of Street-link	1,359	1,096	1,123	1,423	2,237	7,238
Num. of People (*)	16,269	14,336	11,091	22,035	26,321	90,052
Area [km^2]	1.63	1.04	0.77	1.37	1.76	6.57

*) We took into account people inside buildings and pedestrians at 6:00 pm on a weekday, which was estimated on the basis of the person-trip survey conducted in Tokyo Metropolitan Area in 2008. Other people (such as railway passengers, automobile users, etc.) were excluded because we focused on the people's evacuation behavior to major roads from small residential areas surrounded by the roads.

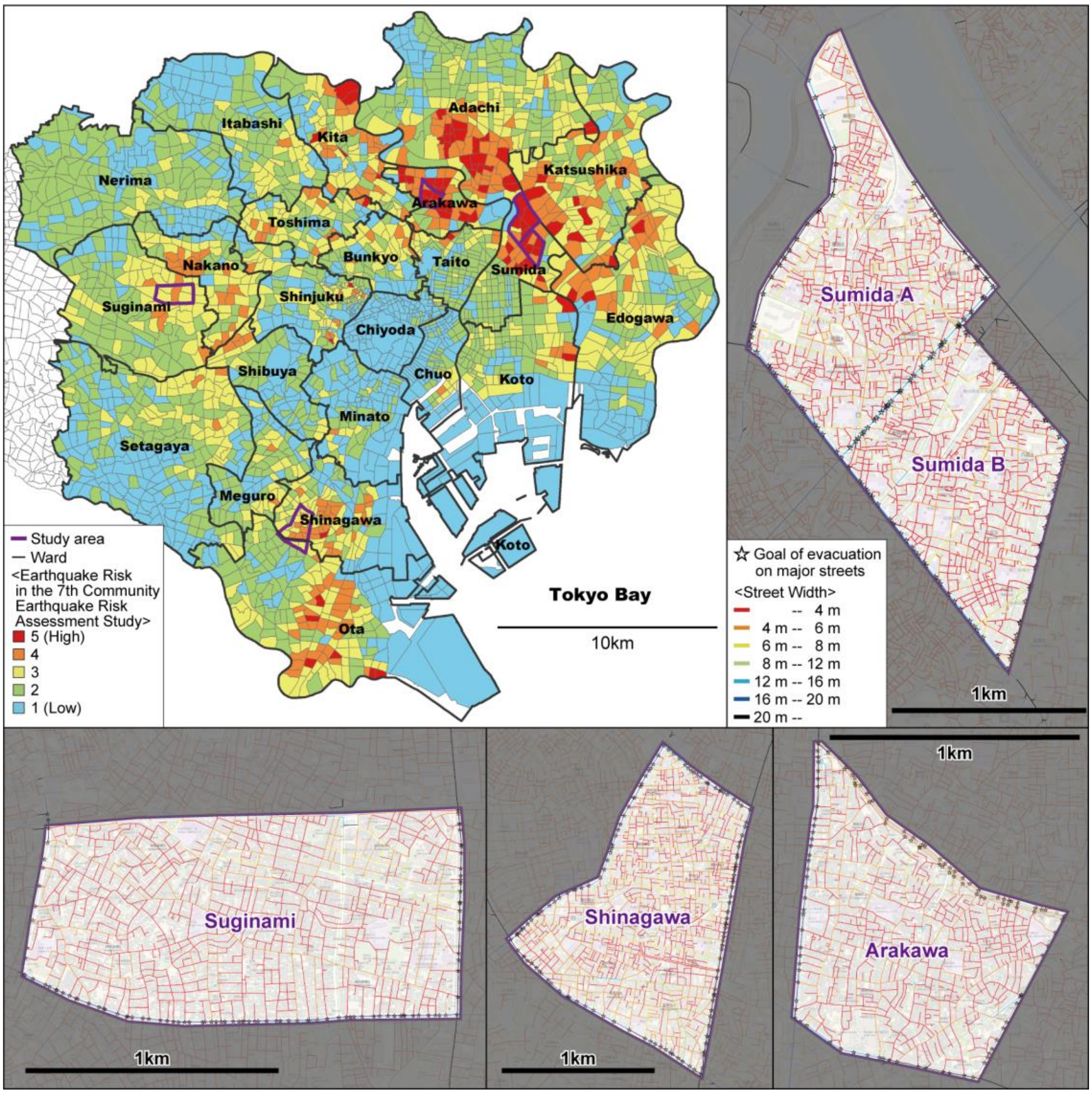


Figure 4. Study Areas for Wide-Area Evacuation Simulation

Change in Ratios of Quake-Resistant Buildings and Property Damage over the Year

Figure 5 shows the change in the ratio of quake-resistant buildings up to 30 years later (based on 2011). As time passes, the number of old buildings, which have high potential of conversion as shown in Figure 2, decreases. Therefore, the increase rate of quake-resistant buildings also gradually decreases. After 30 years, the ratio of quake-resistant buildings becomes more than 80% in most areas, and the difference of the ratio between Sumida A (the lowest ratio) and Suginami (the highest ratio) is reduced by half.

The change in the average ratio of collapsed buildings up to 30 years later is shown in Figure 6. The average ratio of collapsed buildings is much higher in Sumida A, Sumida B, and Arakawa than in the other areas because the ratio of older wooden buildings is higher in these three areas. As a result of conversion, the average ratio of collapsed buildings in these three areas can be reduced to about 10%. We can see the same trend in the average ratio of blocked streets (Figure 7). However, it is noteworthy that the ratio of blocked streets for pedestrians (passable width is 1 m or more) in Arakawa is nearly the same ratio as Suginami and Shinagawa (not Sumida A and Sumida B). This is because there are comparatively more streets with a width of more than 4 m in Arakawa.

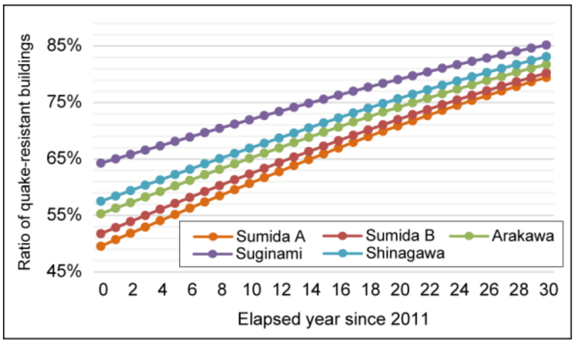


Figure 5. Ratio of Quake-Resistant Buildings

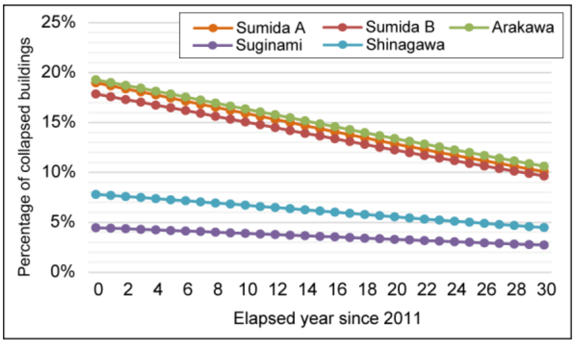
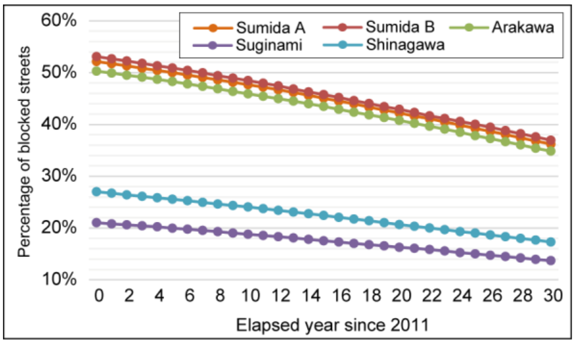


Figure 6. Percentage of Collapsed Buildings



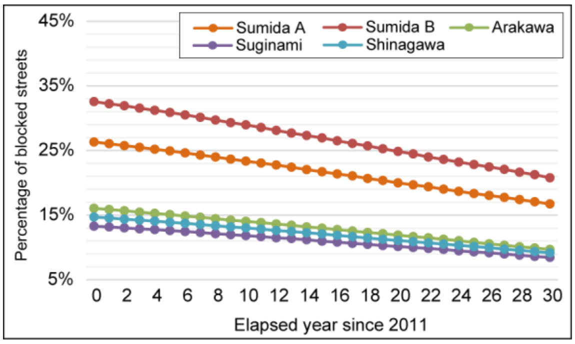


Figure 7. Percentage of Blocked Streets (Left-hand: streets where vehicles cannot pass; Right-hand: streets where both vehicles and pedestrians cannot pass)

Result of Wide-Area Evacuation Simulation

Time/Distance for Arriving at Major Streets

Figure 8 and Figure 9 show the average time and distance of evacuees required for arriving at major streets (hereafter, the results are based on the average values for 100 cases of property damage). The time and distance in the case where no street-blockage occur are indicated by broken lines. The difference of time (distance) between the cases with/without street-blockage is bigger in Sumida A and Shinagawa than in the other areas. The reason is that these two areas are comparatively larger, and therefore, the influence on making a detour in evacuation by street-blockage is also larger. On the other hand, the effects on reducing the difference by conversion of non-quake-resistant buildings are greater in these two areas.

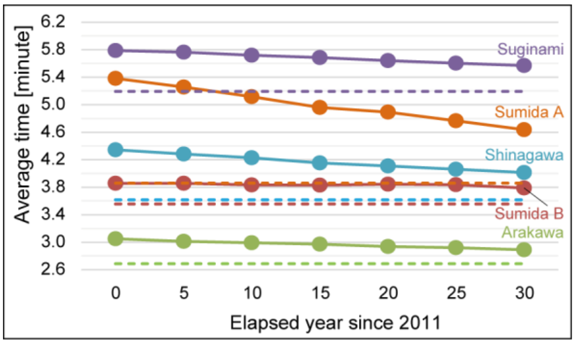


Figure 8. Time for Arriving at Major Streets

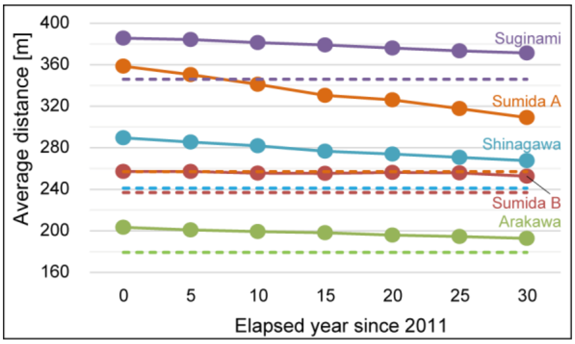


Figure 9. Distance for Arriving at Major Streets

Number of Evacuees Trapped on Streets / in Blocks

We estimated the average number of evacuees trapped on streets (or in blocks) due to street-blockage based on the simulation result (Figure 10). In 2011 (year 0), around 2,000 evacuees are trapped in Sumida A and Sumida B, respectively. Additionally, there are more than 1,000 evacuees trapped on streets (or in blocks) in Shinagawa, where the average ratio of blocked streets is comparatively low in study areas. For easily comparing the results among the study areas, we calculated the ratio of the number of evacuees trapped on streets (or in blocks), divided by total number of people in each area (Figure 11). The magnitude relation of the ratio among five areas corresponds to that of the ratio of blocked streets (Figure 7). After 30 years pass, the number of evacuees trapped on streets (or in blocks) can be reduced by less than half in these three areas.

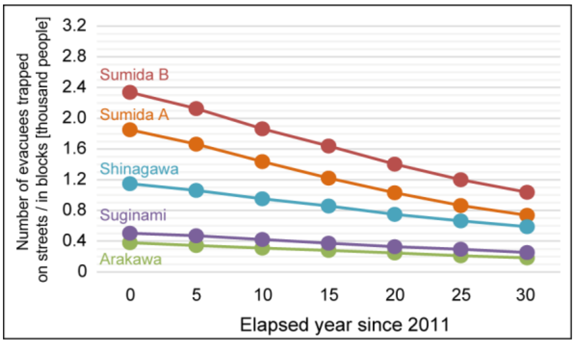


Figure 10. Number of Evacuees Trapped on Streets (or in Blocks)

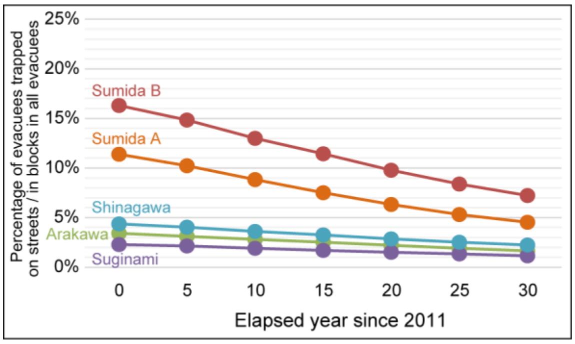


Figure 11. Ratio of Evacuees Trapped on Streets (or in Blocks) in All Evacuees

Number of Encountering Blocked Streets on Evacuation Route

Figure 12 shows the composition ratio in all evacuees by the number of encountering blocked streets on their evacuation route. The ratio of evacuees who encounter blocked streets on their evacuation route at least once decreases by about 10 points after 30 years pass.

Combining the above results, it can be said that the effects of the conversion of non-quake-resistant buildings to quake-resistant ones are not significant from the viewpoint of shortening time and distance for arriving at major streets (Figure 8 and Figure 9). By contrast, the conversion is especially effective in the areas (such as Sumida A and Sumida B) with high risk of street-blockage for reducing the ratio of evacuees trapped on streets (or in blocks) compared with the other areas (Figure 11), which contributes to the reduction of human casualties due to urban fire spread. However, it is noteworthy that the degree of change in all the indices related to wide-area evacuation (Figure 8 to Figure 12) is not yet sufficient even after 30 years pass and much smaller than that in quake-resistant buildings (Figure 5). The results suggest that the conversion of non-quake-resistant buildings is not always directly linked to the reduction of wide-area evacuation difficulty. This is because the conversion of non-quake-resistant buildings is assumed to be proceeded in random order though street-blockage depends on the collapse/non-collapse of all buildings along the street. Our future work will cover analyzing the influence of the order of conversion.

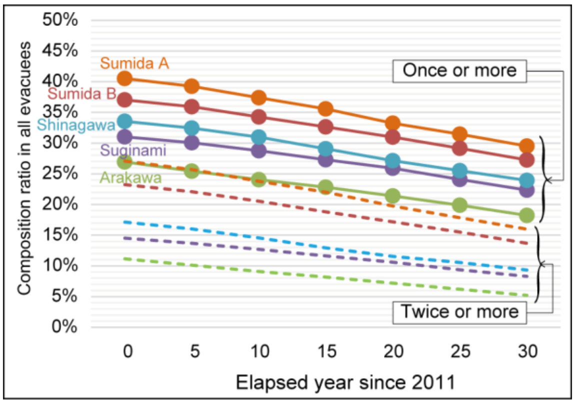


Figure 12. Number of Encountering Blocked Streets on Their Evacuation Route

EVALUATION OF CONVERSION TO QUAKE-RESISTANT BUILDINGS IN TERMS OF FIRE-BRIGADE ACCESSIBILITY

Study Area and Assumptions in Simulation

In this section, we extracted four areas with vulnerable characteristics of streets (such as narrow width, complicated street network, many dead-end streets, etc.) based on the priority development districts (TMG, 2016) and the 7th Community Earthquake Risk Assessment Study (TMG, 2013). Additionally, another three areas with comparatively good characteristics of streets were selected for comparison. The attributes and spatial distribution of these seven areas (1) to (7) are shown in Table 4, Figure 13, and Figure 14. We can also see the spatial distribution of fire stations (starting points of fire-brigades in simulation) and streets in these figures. In some cases, fire stations are located outside the study area. Therefore, fire-brigades were assumed to move to fire origins (burning buildings) by using the streets not only inside each study area but also inside the extended area (within the range of 1.0 km from the perimeter of each study area).

We prepared 500 cases of property damage (building-collapse and street-blockage) estimated by the property damage model in the previous section. The peak ground velocity (PGV) was fixed to 66 [cm/sec]. Herein, for each case, the structure and built year of each building in study areas (hereafter, including the extended areas) were estimated by the procedures mentioned above, and buildings to be converted were randomly extracted from non-quake-resistant buildings. The number of buildings to be converted was determined so that the ratio of quake-resistant buildings in the study area was equal to a certain percentage (from 55% to 100% in increments of 5%: totally 10 steps). Thus, we carried out 5,000 trials (= 500 cases of property damage by 10 steps of the ratio of quake-resistant buildings).

Table 4. Profile of Study Areas (Accessibility of Fire-Brigade)

	Area with Vulnerable Characteristics of Streets				**Area with Comparatively Good Characteristics of Streets**		
Area No.	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Ward	Shinagawa	Suginami	Arakawa	Sumida	Ota	Sumida	Sumida & Koto
Fire station in study area	Ebara Togoshi Hatanodai	Suginami Mabashi Koenji	Arakawa Ogu Shimo-ogu (Tabata*)	Mukoujima Tachibana	Ichinokura Kugahara Yaguchi Shimo-maruko Nishi-kamata	Honjo Higashi-komagata (Asakusa*)	Midori* Morishita* (Hamacho*)
Area [km^2]	1.41	0.85	0.77	1.04	1.30	0.74	1.11
Daytime population [person] ([person/km^2])	25,143 (17,886)	18,776 (22,056)	13,841 (17,951)	17,786 (17,156)	22,580 (17,407)	14,979 (20,346)	24,057 (21,749)
Nighttime population [person] ([person/km^2])	35,917 (25,550)	19,017 (22,339)	19,489 (25,276)	21,996 (21,217)	29,693 (22,891)	13,830 (18,785)	25,750 (23,280)
Daytime/ Nighttime	0.70	0.99	0.71	0.81	0.76	1.08	0.93

*) In principle, firefighters take care of fires only in the ward where their fire station is located. Therefore, we assumed that: (i) Firefighters belonging to Midori Fire Station and Morishita Fire Station (Area (7)) headed for the fires which broke out in Sumida Ward and Koto Ward, respectively; (ii) Tabata Fire Station (Area (3)), Asakusa Fire Station (Area (6)), and Hamacho Fire Station (Area (7)) were excluded from the simulation because these were located in the different ward from the one where each study area was located.

**) Daytime and nighttime population are based on the National Census in 2010.

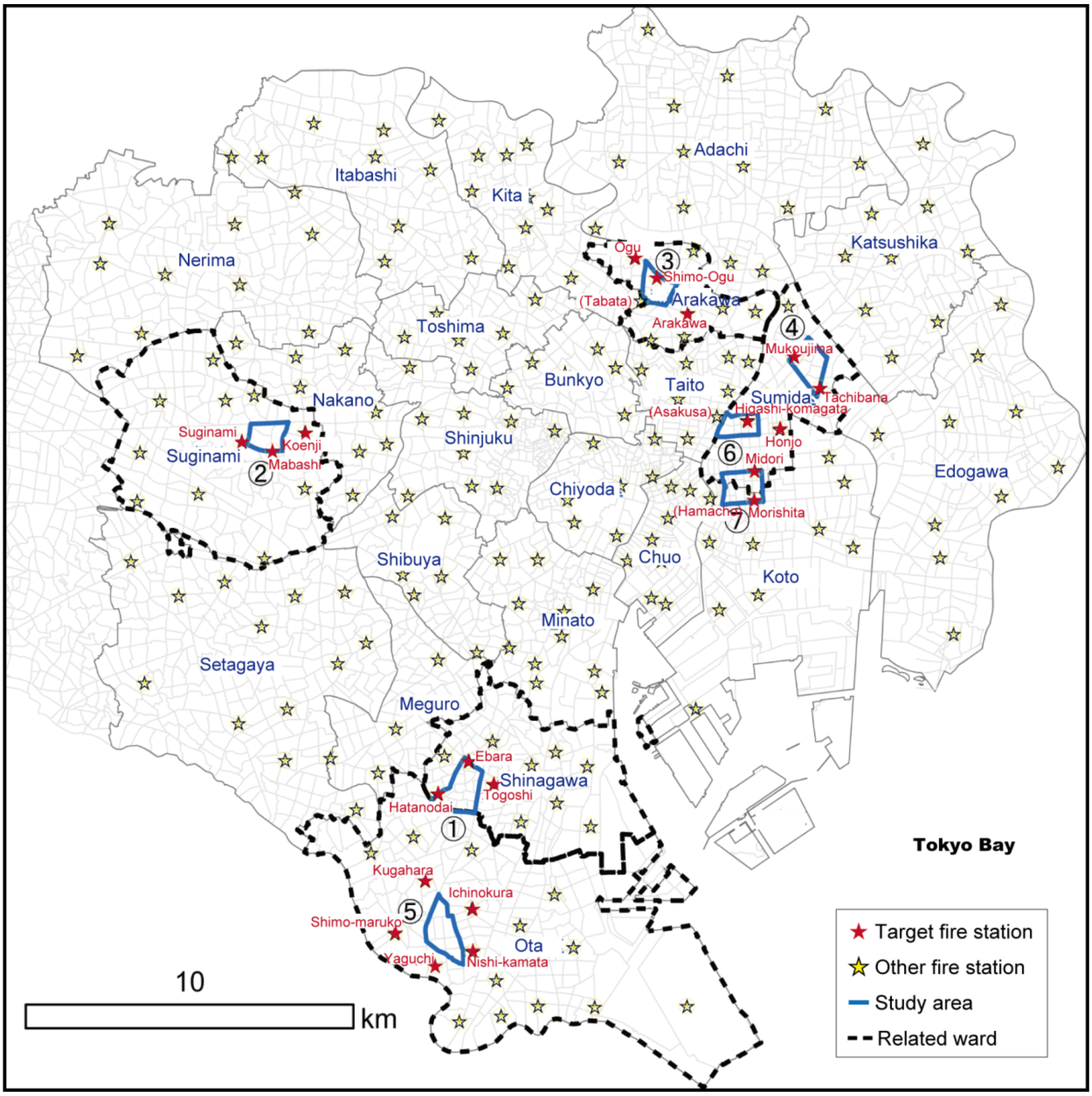


Figure 13. Spatial Distribution of Study Areas and Fire Stations

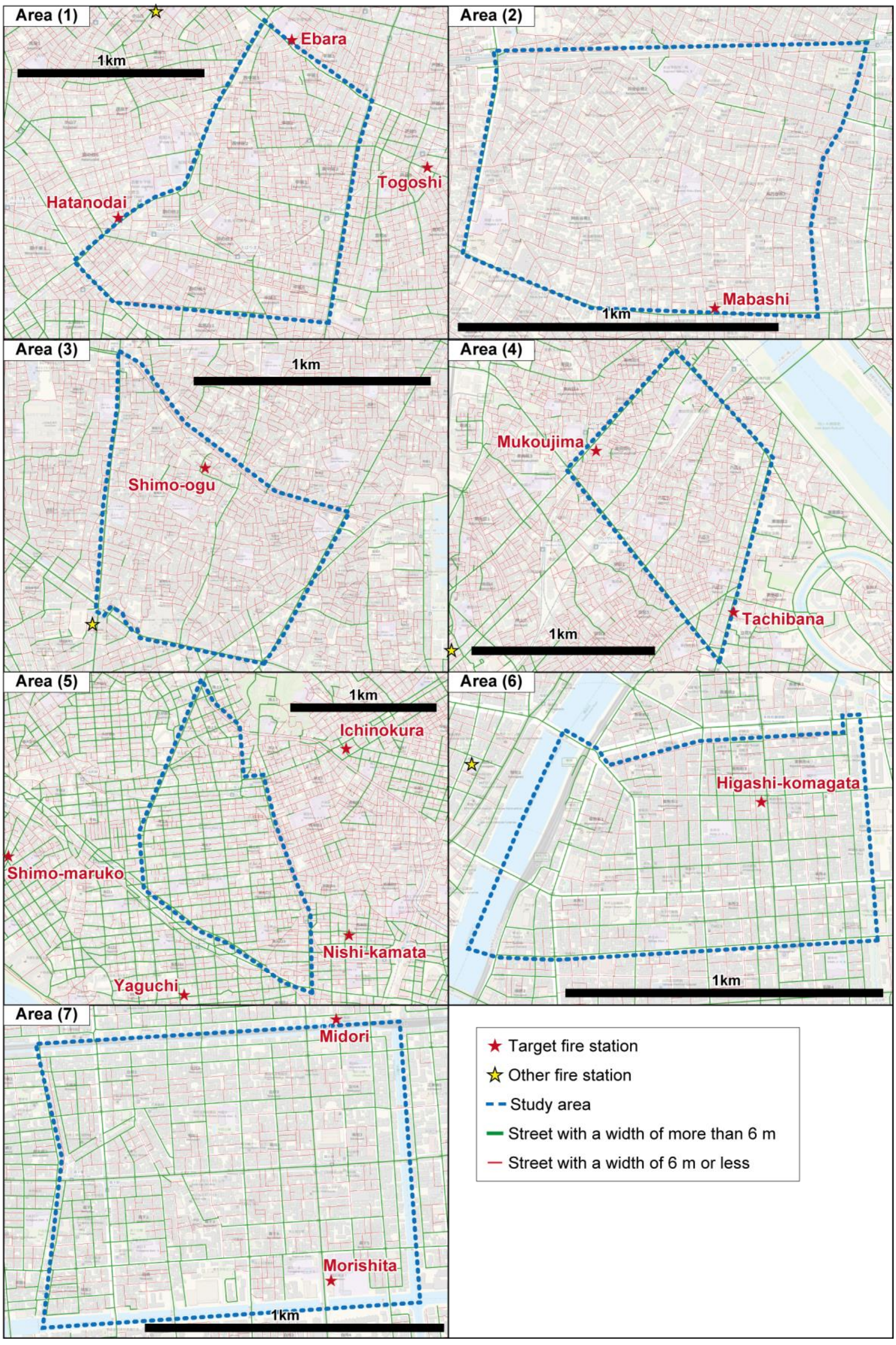


Figure 14. Detail of Study Areas

Reducing the Numbers of Collapsed Buildings / Blocked Streets by Promoting Conversion to Quake-Resistant Buildings

Table 5 shows the ratio of quake-resistant buildings in each area (as of 2011). The ratio is less than 40% in areas (4) and (6), while more than 50% in areas (2) and (5).

Table 5. Ratio of Quake-Resistant Buildings in Each Area (in 2011)

	Area with Vulnerable Characteristics of Streets				Area with Comparatively Good Characteristics of Streets		
Area No.	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Built in 1981 or later	3,718	2,240	2,180	2,022	3,018	1,128	2,010
Built before 1980	4,412	2,012	2,716	3,748	2,640	2,004	2,812
Total	8,130	4,252	4,896	5,770	5,658	3,132	4,822
Ratio of quake-resistant buildings	45.7%	52.7%	44.5%	35.0%	53.3%	36.0%	41.7%

Figure 15 shows the reduction of the number of collapsed buildings and blocked streets by promoting conversion to quake-resistant buildings. There is little difference among study areas in the relationship between the ratio of quake-resistant buildings and the average ratio of collapsed buildings (Figure 15, left-hand panel). In other words, the ratio of collapsed buildings is nearly the same in the areas with nearly the same ratio of quake-resistant buildings. By contrast, the average ratio of blocked streets in the areas with vulnerable characteristics of streets (areas (1) to (4)) is about twice as large as the ratio in the areas with comparatively good characteristics of streets (areas (5) to (7)) in case of the same ratio of quake-resistant buildings (Figure 15, right-hand panel).

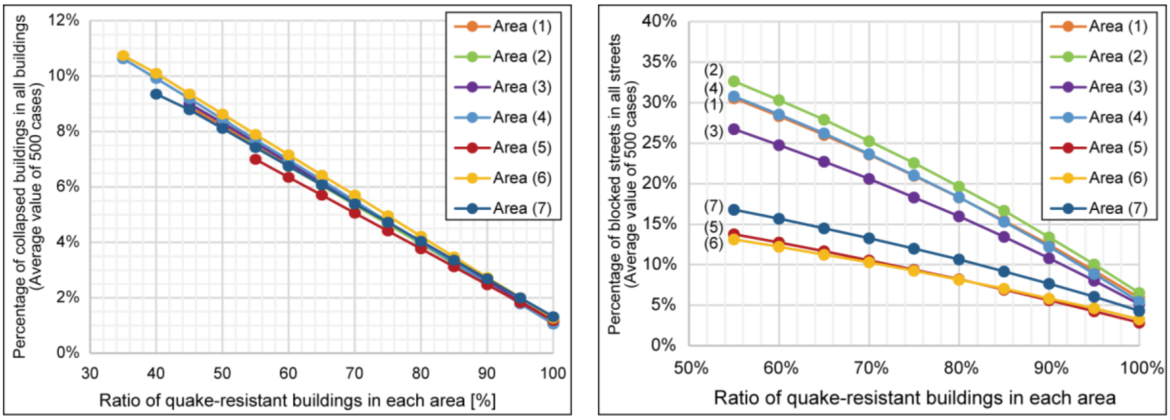


Figure 15. Relationships between Ratio of Quake-Resistant Buildings and Percentages of Collapsed Buildings and Blocked Streets

Access Time to Fires in Normal Times (without Street-Blockage)

As seen in Table 6, there is a big difference in the access time to fires under the condition without street-blockage according to the size of study area or the location of fire stations. Therefore, hereafter, in order to easily compare among multiple study areas, a fire origin was randomly extracted from the buildings where the travel time in case that no street-blockage occur (Figure 16) was 2.0 minutes to 2.5 minutes in each area for each simulation trial. Among the specific property damage case (with/without street-blockage), the location of a fire origin was the same and a fire-brigade headed from the same fire station, independent of the ratio of quake-resistant buildings.

Table 6. Time Required for Fire-Brigades to Arrive at a Building in Each Area

			Area with Vulnerable Characteristics of Streets				Area with Comparatively Good Characteristics of Streets		
		All	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Num. of buildings		36,660	8,130	4,252	4,896	5,770	5,658	3,132	4,822
Time [m:ss]	Ave.	1:29	1:18	1:38	1:15	1:28	1:45	2:04	1:11
	St. Dev.	0:35	0:29	0:37	0:28	0:38	0:26	0:24	0:32
	Max.	4:07	3:16	3:51	2:47	3:29	3:07	3:25	4:07

*) Each time in this table was calculated on the basis of simulation results for all buildings in the area.

**) In Area (6), the size of the area is small and a fire station (Higashi-komagata) is located nearly at the center of the area. Therefore, there are originally few buildings where fire-brigades take 2 minutes to 2 minutes 30 seconds in normal times. However, for comparison with the results in the other areas, we analyze the access time in Area (6) based on the time required only from another fire station (Honjo) (Table 6 and Figure 16(b)).

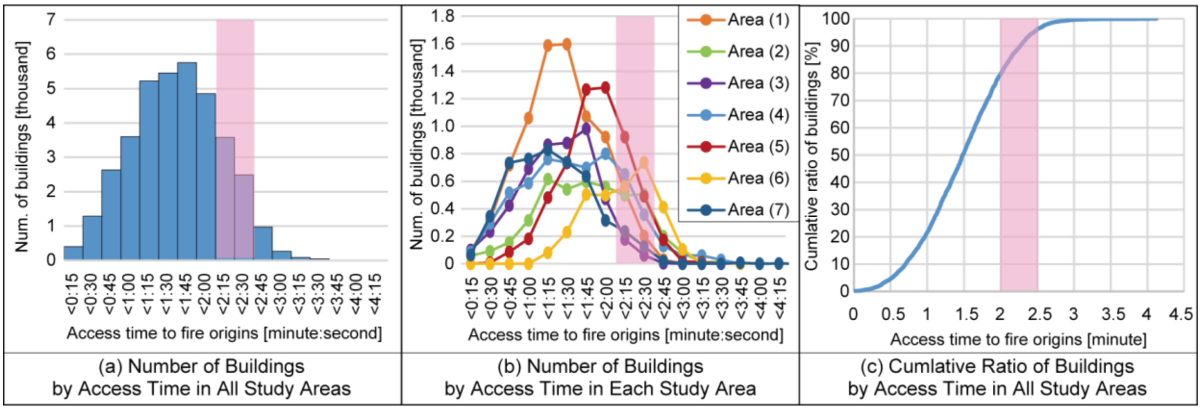


Figure 16. Access Time to Fire Origins (in the Case without Street-Blockage)

Shortening Access Time to Fires by Promoting Conversion to Quake-Resistant Buildings

Firstly, we assumed that streets with a width of more than 6 m were never blocked by rubbles of collapsed buildings in order to evaluate the effects of shortening access time by converting buildings along narrow streets to quake-resistant ones.

The relationships between the ratio of quake-resistant buildings and access time to fires are shown in Figure 17 (left-hand panel: average value; right-hand panel: maximum value). In the areas with comparatively good characteristics of streets (areas (5) to (7)), there is a slight improvement in access time because the ratio of blocked streets is comparatively low (Figure 15, right-hand panel). By contrast, in the other areas (areas (1) to (4)), the accessibility of fire-brigades is improved as the ratio of quake-resistant buildings increases, and therefore the average/maximum time required for travelling to fire origins can be greatly shortened. Specifically, the difference of access time with/without street-blockage is much bigger in Area (2) than in the other areas because there are few streets with a width of more than 6 m [1)]. However, the difference becomes significantly smaller and access time becomes closer to the time in the case with no street-blockages.

These results suggest that the effects of shortening access time to fires are larger in the areas with more vulnerable characteristics of streets. Considering the possibility that streets with a width of more than 6 m are blocked, the effects are further remarkable (Figure 18).

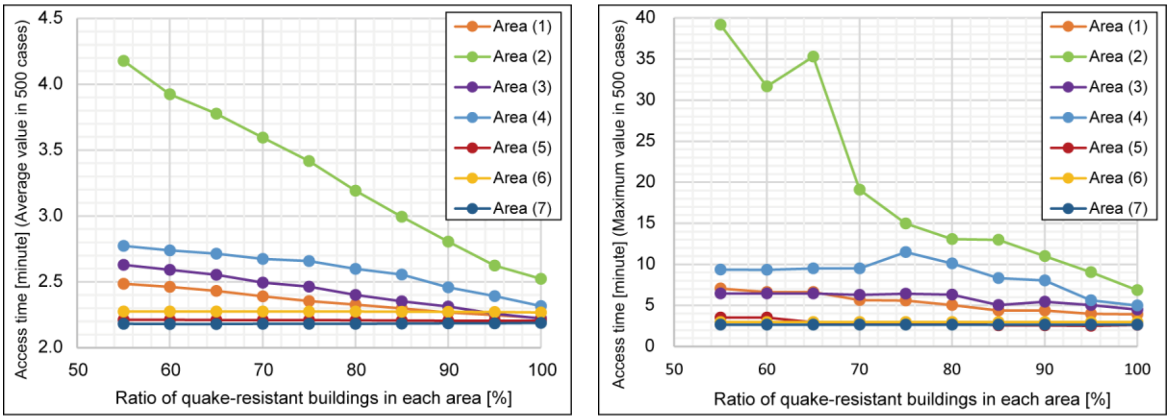


Figure 17. Relationship between Ratio of Quake-Resistant Buildings and Access Time of Fire-Brigade (Not Considering Blockage of Streets with a Width of More than 6 m)

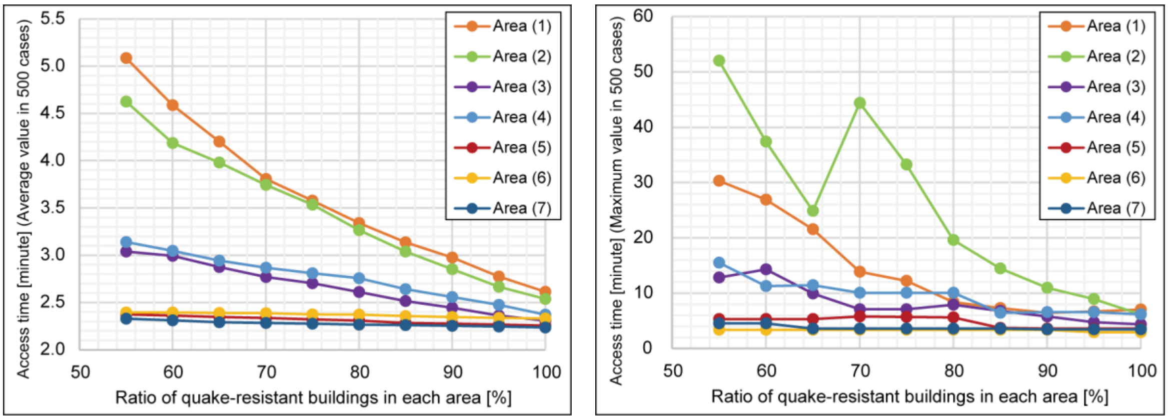


Figure 18. Relationship between Ratio of Quake-Resistant Buildings and Access Time of Fire-Brigade (Considering Blockage of Streets with a Width of More than 6 m)

SUMMARY AND CONCLUSIONS

Conversion of low quake-resistant buildings to quake-resistant ones has been important issue for the reduction of property and human damage in densely built-up wooden residential areas at the time of a large earthquake. Aiming at evaluating conversion of such buildings from multiple aspects related to human activities, we implemented the simulations in multiple study areas by using the models which described conversion to quake-resistant building, building-collapse, street-blockage, wide-area evacuation behavior, and activities of fire-brigade. The main results of the simulations can be summarized as follows:

- The ratios of collapsed buildings and blocked streets can decrease in all the study areas as the ratio of quake-resistant buildings increases.
- The influence on making a detour in evacuation by street-blockage tends to be larger in wider areas. Therefore, the effects on reducing the difference of time (or distance) between the cases with/without street-blockage by conversion of low quake-resistant buildings are greater in such areas.
- The magnitude relation of the ratio of evacuees trapped on streets (or in blocks) among the study areas corresponds to that of the ratio of blocked streets. In other words, the areas where more buildings with low resistance to earthquake have a higher potential of reducing the ratio of evacuees with the difficulty in wide-area evacuation.
- The effects of shortening access time of fire-brigades to fire origins are larger in the areas with more vulnerable characteristics of streets (i.e., the areas where almost all streets are narrow).

Using the analytical method proposed in this paper, we can evaluate conversion to quake-resistant buildings in terms of both wide-area evacuation and fire-brigade accessibility in any area. Additionally, it is possible to provide information for making a decision of more effective and efficient methods of converting buildings. For instance, the priority of providing subsidies for reconstruction among multiple areas or in the specific area can be considered based on the quantitative evidence by comparing simulation results under the condition of different conversion scenarios.

NOTES

1) The graphs of Area (2) in the right-hand panels of Figure 17 and 18 are discontinuous. As described in Section "Activity of Fire-Brigade", the cases where a fire-brigade cannot reach a fire origin due to street-blockage are excluded in the calculation of the access time. Namely, the results in Area (2) suggest that: if the ratio of quake-resistant buildings increases from 60% to 65%, the possibility that fire-brigades reach the fire origin increases but they have to make a long detour in critical cases as well.

ACKNOWLEDGMENTS

The authors would like to express sincere thanks to Tokyo Metropolitan Government and Tokyo Fire Department for their collaborations and for providing a portion of the data used in this paper.

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An Agile Framework for Detecting and Quantifying Hazardous Gas Releases

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ABSTRACT

In response to the threat of hazardous gas releases to public safety and health, we propose an agile framework for detecting and quantifying gas emission sources. Emerging techniques like high-precision gas sensors, source term estimation algorithms and Unmanned Aerial Vehicles are incorporated. The framework takes advantage of both stationary sensor network method and mobile sensing approach for the detection and quantification of hazardous gases from fugitive, accidental or deliberate releases. Preliminary results on street-level detection of urban natural gas leakage is presented. Source term estimation is demonstrated through a synthetic test case, and is verified using Cramér–Rao bound analysis.

Keywords

Hazardous gas release, mobile sensing, data fusion, leakage detection, source term estimation

INTRODUCTION

The threat of hazardous gas releases to public safety and health is enormous. The causes of hazardous gas releases include accidental or fugitive emissions related to industries (Gupta, 2002) and deliberate releases due to terrorist attacks (Yanagisawa et al, 2006).

To facilitate the emergency response for hazardous gas releases, considerable effort has been devoted to designing leakage detection and localization techniques (Murvay and Silea, 2012; Liu et al., 2015; Zhang et al., 2015, 2017). Source term estimation (STE) means to infer the location and release rate based on meteorological observations, sensor measurements and domain knowledge like atmospheric dispersion models (Wang et al., 2015a; Hutchinson et al., 2017). Now there are mainly four categories of source term estimation methods: direct method (Bady et al., 2009), optimization method (Ma et al., 2013; Kumar et al., 2016), Bayesian inference method (Keats et al., 2010; Ristic et al., 2015a; Wang et al., 2017) and nonlinear regression method (Wang et al., 2015b). The direct method requires high resolution wind and concentration information over the whole computational domain, which is difficult to satisfy in real world applications. The nonlinear regression method requires enormous training data, so its application is limited to those situations where a large number of atmospheric dispersion experiments or simulation are available. The remaining optimization method and Bayesian inference method are the most flexible ones because they only require very sparse wind and concentration measurements. Both optimization method and Bayesian inference method work in an iterative way, which normally requires enormous runs of a forward atmospheric dispersion model to find the best estimate of the source parameters.

In recent years, emerging sensor technologies have been coupled with vehicles to measure the methane leakage under streets and generate maps of natural gas leaks in a faster and cheaper way (Phillips et al., 2013; Jackson et al., 2014), showing that urban natural gas distribution systems have a very large number of leaks. To better quantify the situation, many modelling efforts are devoted to the quantification of methane leakage from oil and gas industry based on either stationary measurement (Foster-Wittig et al., 2015) or mobile sensing approach (Albertson et al., 2016), which constitutes an important application field of source term estimation techniques.

In this paper, we present an agile framework for detecting and quantifying hazardous gas releases based on emerging techniques like high-precision gas sensors, source term estimation algorithms and Unmanned Aerial Vehicles (UAVs). In normal conditions, our gas sensors can explore human settlement to detect and quantify fugitive gas releases like methane from urban natural gas network; in emergency conditions, our gas sensors can be deployed agilely to the concerned spot to enhance situation awareness by concentration measurement and source term estimation. Preliminary results on the street-level detection of urban natural gas leakage is presented. Source term estimation technique is demonstrated through a synthetic test case, and is verified using Cramér–Rao bound analysis.

THE OVERALL FRAMEWORK

The gas detection and estimation framework consists of three kinds of sensor nodes (stationary sensors, vehicles and UAVs) and an advanced data fusion algorithm based on Bayesian inference to estimate the location and strength of emission sources. An illustration of the workflow of the proposed framework is in Figure 1. Raw data collection and signal processing are done in sensor nodes equipped with microcontrollers, which will upload sensor observations to data center through WIFI or GPRS. In data processing stage, sensor observations are clustered according to their geographic positions given by GPS modules on the sensor nodes. Then anomaly detection of time series is conducted to catch elevated concentration observations, after which data fusion algorithms are utilized to estimate the leakage location and emission rate.

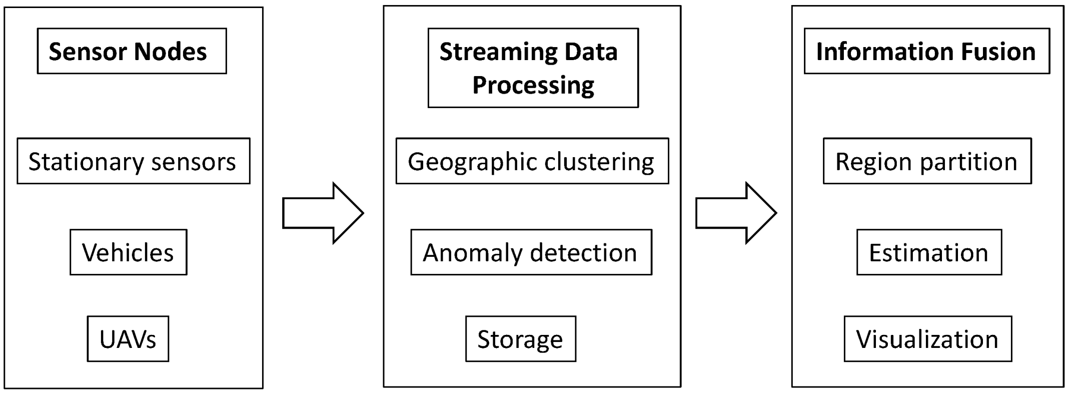
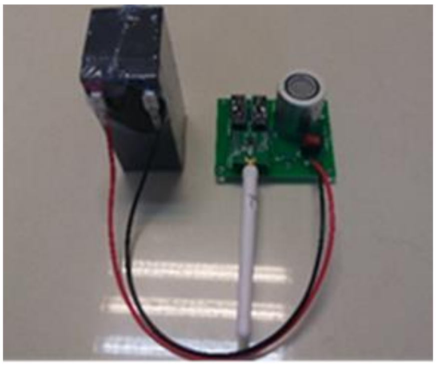


Figure 1. Workflow of the Proposed Framework

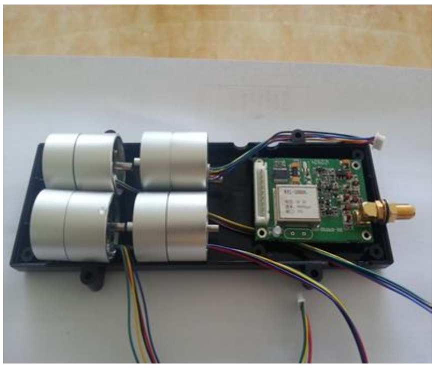
We developed three kinds of sensor nodes (stationary sensors, vehicles and UAVs). Stationary sensors are normally deployed in those places of high risk like chemical plants or high vulnerability like schools and hospitals to enable the early detection of hazardous gas releases. The limitation of stationary sensor networks is that it is infeasible to effectively cover all areas of concern because the emission location due to accidents and terrorist attacks is unpredictable. To address this issue, vehicles and UAVs are equipped with high-precision gas sensors and GPS modules to enable fast and large-scale measurement and mapping of gas concentration. In addition, UAVs can approach very dangerous places where emergency responders cannot enter and is normally not restricted by the terrain. A prototype stationary sensor node is shown in Figure 2(a). A vehicle equipped with high-precision methane sensors is shown in Figure 2(b). The multi-rotor UAV product and the multi-component gas sensors mounted on it are shown in Figure 2(c) and Figure 2(d), respectively.



(a)

(b)

(c)



(d)

Figure 2. Sensor Nodes Development

DATA FUSION ALGORITHMS

Bayesian Inference

Let $\boldsymbol{\theta}$ denote the source parameter vector containing source location $[x_0, y_0, z_0]$ and emission rate Q_0. Let $\mathbf{z}$ = $[z_1, z_2, \ldots, z_n]$ denote the concentration observations of n gas sensors. According to the Bayes' theorem, the posterior probability of the parameter vector $\boldsymbol{\theta}$ is given by:

$$p(\boldsymbol{\theta} \mid \mathbf{z}, I) = \frac{p(\mathbf{z} \mid \boldsymbol{\theta}, I)\, p(\boldsymbol{\theta} \mid I)}{p(\mathbf{z} \mid I)}$$

where I is relevant background information such as meteorological conditions and land use situation, $p(\mathbf{z} \mid \boldsymbol{\theta}, I)$ is the likelihood function, $p(\boldsymbol{\theta} \mid I)$ is the prior distribution, $p(\mathbf{z} \mid I)$ is the marginal distribution of the observations and is computed as the integral of $p(\mathbf{z} \mid \boldsymbol{\theta}, I)\, p(\boldsymbol{\theta} \mid I)$ over $\boldsymbol{\theta}$.

Likelihood Function

In Bayesian source term estimation, likelihood function is used to describe the information about the measurement noise and modelling uncertainties (Kaipio and Somersalo, 2006). Following previous studies (Keats et al, 2010; Albertson et al, 2016), we adopt the normal distribution as the likelihood function:

$$p(\mathbf{z} \mid \boldsymbol{\theta}) = \prod_{i=1}^{n} p(\mathrm{z}_i \mid \boldsymbol{\theta}) = \left(\frac{\tau}{2\pi}\right)^{\frac{n}{2}} \exp\left\{-\sum_{i=1}^{n} \frac{\tau}{2}[F_i(\boldsymbol{\theta}) - \mathrm{z}_i]^2\right\}$$

where $F_i(\boldsymbol{\theta})$ is the prediction of the forward dispersion model at sensor *i*, τ is the scale parameter of normal distribution. The widely used Gaussian plume model is chosen to be the forward dispersion model, which predicts the concentration at point (x, y, z) as

$$C(\boldsymbol{\theta}) = \frac{Q_0}{2\pi U \sigma_y \sigma_z} \exp(-\frac{1}{2} \cdot \frac{(y-y_0)^2}{\sigma_y^2}) \cdot \left\{ \exp\left[-\frac{1}{2} \cdot \frac{(z-z_0)^2}{\sigma_z^2} \right] + \exp\left[-\frac{1}{2} \cdot \frac{(z+z_0)^2}{\sigma_z^2} \right] \right\}$$

where U is the wind speed, σ_y and σ_z are model parameters related to terrain, atmospheric stability and the downwind distance x- x_0 between point (x, y, z) and emission source (x_0, y_0, z_0) (Briggs, 1973). If we consider the dispersion process and concentration distribution more elaborately (e.g. Efthimiou et al., 2016), we may turn to more complex forward dispersion models and choose more suitable likelihood functions (Wang et al., 2017).

Prior Distribution

Prior distribution represents the initial guess of source parameters before the fusion of information by Bayesian source term estimation. According to Sivia and Skilling (2006), complete ignorance for location parameters $[x_0, y_0, z_0]$ is to use a uniform distribution, and that for scale parameters $[Q_0, \tau]$ is to use Jeffreys' prior:

$$p(Q_0|I) = 1/Q_0, Q_0 > 0$$

$$p(\tau|I) = 1/\tau, \tau > 0$$

To assign the prior distribution for location parameters, we need do region partition in the area concerned to form computational domains. In each computational domain, we assume that there is only one emission source, to which all the measured concentrations are attributed.

Note that reasonable prior information can help regularize the source term estimation problem, leading to faster convergence and tighter posterior estimates, especially under unfavorable meteorological conditions where the quality of sensor measurement is not sufficient to provide satisfactory estimates.

Stochastic Sampling

Several stochastic sampling algorithms for calculating the posterior distribution of source parameters are investigated in previous work (Wang et al., 2015a; Ristic et al., 2017), including Markov chain Monte Carlo, sequential Monte Carlo (or particle filter) and ensemble Kalman filter. In this paper, a very efficient version of the sequential Monte Carlo method called regularized particle filter (RPF) (Musso et al., 2001) is adopted. The pseudocode of the regularized particle filter is given in Algorithm 1, where the variable h_{opt} is the optimal bandwidth for Gaussian kernel (Musso et al., 2001). A newly proposed minimum-sampling-variance resampling scheme (Li et al., 2015) is used to alleviate the sample degeneracy problem where large computational effort is wasted in particles which only have negligible contribution to the estimation of posterior distribution. The regularization step is used to jitter the resampled particles (improve the sample diversity) to avoid particle collapse where all the particles occupy the same place in the state space.

Algorithm 1. Regularized Particle Filter (RPF)

Input: prior distribution of the target vector $p(\boldsymbol{\theta}|I)$, the likelihood function $p(\mathbf{z}|\boldsymbol{\theta}, I)$, concentration observations **z**, number of particles N, proposal distribution $q_t(*|\boldsymbol{\theta}*)$, maximum iteration number $t_{\max}$

Output: weighted particles representing the posterior distribution: $\{\boldsymbol{\theta}^{(i,t)}, w^{(i,t)}\}_{1\le i\le N}, t = 1, 2, ...T$

```
Set t = 0
while t ≤ t_max do
Set n = 1
    if t = 0
        Draw N particles {θ^(i,t)}_{1≤i≤N} from the prior distribution p(θ|I)
        Set w^(i,t) = 1/N, 1 ≤ i ≤ N
    end if
    if t > 0
        while n ≤ N do
            Draw θ* from the proposal distribution q_t(* |θ^(n,t-1))
            Set n = n + 1
```

Set $\boldsymbol{\theta}^{(n,t)} = \boldsymbol{\theta}^*$
Set $w^{(n,t)} = p(\mathbf{z}|\boldsymbol{\theta}^{(n,t)}, I)$
end while
end if
Normalize the weights $\{w^{(i,t)}\}_{1 \le i \le N}$
if $ESS = \left[\sum_{i=1}^{N}(w^{(i,t)})^2\right]^{-1} < \frac{1}{2}N$
Calculate the empirical covariance matrix $\mathbf{S}_\mathbf{k}$ of $\{\boldsymbol{\theta}^{(i,t)}, w^{(i,t)}\}_{1 \le i \le N}$
Compute $\mathbf{D}_\mathbf{k}$ such that $\mathbf{D}_\mathbf{k}\mathbf{D}_\mathbf{k}^T = \mathbf{S}_\mathbf{k}$
Resample the particles
for i =1: N
Draw ϵ^i from Gaussian kernel **N**(0,1)
Set $\boldsymbol{\theta}^{(n,t)} = \boldsymbol{\theta}^{(n,t)} + h_{opt}\mathbf{D}_k\epsilon^i$ //regularization step
end for
end if
$t = t + 1$
end while

Cramér–Rao Bound

The Cramér–Rao bound (CRB) gives a theoretical lower bound for the covariance matrix (or precision) of any unbiased estimator, which can serve as a benchmark for evaluating the performance of different algorithms and setups for estimation purposes. With CRB, the best achievable accuracy of a STE system (including the selection of forward dispersion models, the placement of sensors, meteorological conditions, data fusion algorithms, etc.) can be evaluated theoretically even before actually running STE algorithms.

Details of the derivation of Cramér–Rao bound for a simplified Gaussian plume model is given in Ristic et al. (2015b), a ready-to-use source code based on symbolic computation is also available for calculating the Cramér–Rao bound for more complex dispersion models (Ristic et al., 2017).

PRELIMINARY RESULTS AND DISCUSSION

Field Measurement

We use the street-level detection of urban natural gas network leakage as an example. The concentration distribution along the driving path is shown in Figure 3. The maximum observed concentration is only 12.42 ppm. In addition, the observed elevated concentration is very sparse and is shown in Figure 4.

Figure 3. Concentration Distribution of Methane Along the Driving Path (ppm)

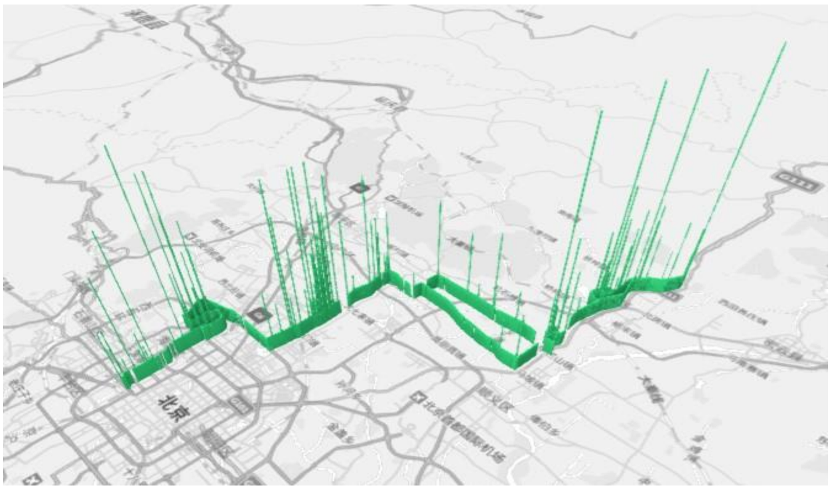


Figure 4. Sparse Elevated Values of Methane Concentration Along the Driving Path

This mobile sensing approach enables large-scale gas-concentration mapping, which can enhance our knowledge and understandings of urban natural gas leakage. However, estimating the leakage rate and location of urban buried natural gas networks based on this kind of street-level methane mapping proved to be a very challenging task (von Fischer et al., 2013a, 2013b; Burba et al., 2016). We are still working on the meaningful interpretation of these methane maps and sparse elevated concentration observations.

Leakage Quantification

To demonstrate the source term estimation functionality, we assume that a leakage is already detected by a sensor array shown in Figure 5. Now the task is to estimate the leakage location and emission rate. The true value of the target source parameter vector $\boldsymbol{\theta} = [x_0, y_0, z_0, Q_0]$ is $[0\ \ \mathrm{m}, 10\ \ \mathrm{m}, 8\ \ \mathrm{m}, 20\ \ \mathrm{g/s}]$. The average wind speed is 3.5 m/s. The atmospheric stability class is D, which corresponds to neutral conditions. For simplicity, Gaussian distribution is chosen to be the prior distribution, where the mean value is zero and the standard deviation for each variable is given in Table 1 as the prior uncertainty. As can be seen in Table 1, the point estimate given by the mean value of the posterior distribution agrees well with the true values of the source parameters. The estimation precision demonstrated by the posterior uncertainty is approaching the best achievable accuracy given by Cramér–Rao bound, showing that the data fusion algorithm is effective.

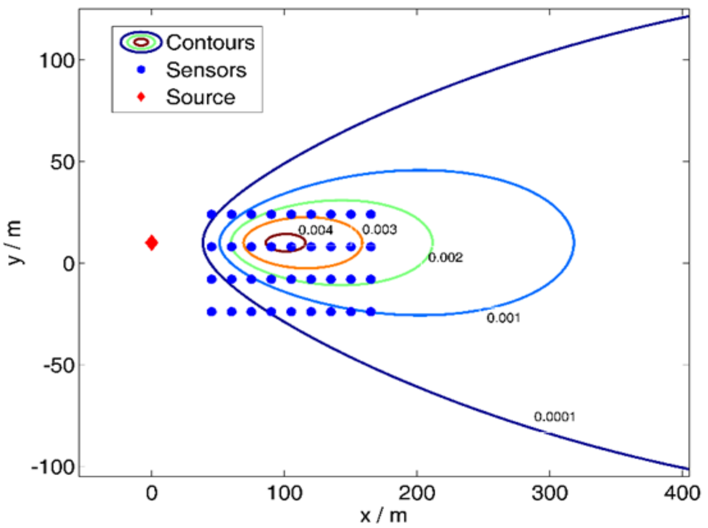


Figure 5. Schematics of the Experiment Setup and Contours of the Concentration on the Ground Level by Gaussian Plume Model (g/m^3)

Table 1. Results of Source Term Estimation and Best Achievable Accuracy Given by Cramér–Rao Bound

	Point estimate	Prior uncertainty	Posterior uncertainty	Best achievable accuracy
x_0	-0.050	500	0.900	0.742
y_0	10.022	500	0.114	0.106
z_0	8.004	3	0.100	0.088
Q_0	20.000	3	0.431	0.458

CONSLUSIONS AND FUTURE WORK

In this paper, an agile framework for detecting and quantifying gas emission sources is proposed, which incorporates stationary sensor networks, vehicles and UAVs equipped with gas sensors, and data fusion algorithms based on Bayesian inference. The mobile sensing approach based on vehicles is applied to street level measurement of methane leakage from urban buried natural gas network. The source term estimation technique is applied to a simulated test case and is verified by theoretical analysis using Cramér–Rao bound. Preliminary results prove the effectiveness of the street-level mobile sensing approach and leakage quantification algorithms.

The proposed framework can enhance the flexibility and agility of hazardous gas detection and quantification. Future work will be devoted to conducting field experiments to better test the performance of the proposed framework. Also, autonomous search strategies of UAVs for hazardous gas releases will be investigated to build a more intelligent system.

ACKNOWLEDGMENTS

This work was supported by the Ministry of Science and Technology of the People´s Republic of China under Grant No. 2015BAK12B01 and 2016YFC0802501 and National Natural Science Foundation of China (Grant No. 71473146).

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Solving the earthquake disaster shelter location-allocation problem using optimization heuristics

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ABSTRACT

Earthquakes can cause significant disruption and devastation to populations of communities. Thus, in the event of an earthquake, it is necessary to have the right number of disaster shelters, with the appropriate capacity, in the right location in order to accommodate local communities. Mathematical models, allied with suitable optimization algorithms, have been used to determine the locations at which to construct disaster shelters and allocate the population to them. This paper compares the use of two optimization algorithms, namely a genetic algorithm and a modified particle swarm optimization, both of which have advantages and disadvantages when solving the disaster shelter location-allocation problem.

Keywords

Earthquake shelter location-allocation, multi-objective optimization, GA, MPSO.

INTRODUCTION

Natural disasters, such as floods, earthquakes and hurricanes, can result in significant losses in human life, along with serious injuries to people, as well as damage and disruption accounting for significant economic losses (EM-DAT, 2016). Natural disasters caused 23880 deaths in 2015 and 6860 deaths in 2016 (EM-DAT,2016). According to EM-DAT (2016), from 2000-2016, there has been 714654 deaths caused by earthquakes, 92191 deaths by floods, and 192748 deaths by storms, which indicates that natural disasters, in particular earthquakes, have a significant cost in terms of loss of life. In monetary terms, natural catastrophes caused economic losses of USD 74 billion in 2015 (Swiss Re, 2015) and USD 68 billion in the first half of 2016 (Swiss Re, 2016). In relation to the Nepal earthquake in 2015, more than 9,000 people lost their lives and an economic loss of more than USD 6 billion was estimated (Swiss, 2015). Other earthquake events, such as those that occurred in China in 2008 (Yuan, 2008; Zhang et al. 2010), Japan in 2011 (Norio et al., 2011) and Haiti in 2010 (Bilham, 2011), have led to loss of life and seriously affected the lives of others.

To reduce the damage caused by earthquakes, many engineering techniques have been proposed to enhance the resilience of buildings (Chen and Scawthorn, 2002). However, in cases where buildings cannot protect people, there is a need to ensure there are a sufficient number of disaster shelters, with adequate capacity, situated in locations that people can reach quickly. Constructing disaster shelters to be used in emergency situations is one of the most effective methods to help ensure people’s safety. For example, approximately 250,000 people were housed in emergency shelters after the 2011 earthquake and tsunami in Japan (BBC, 2011), which assisted the government in rescuing people quickly.

Selecting shelter locations, and establishing how a population can be allocated to these shelters, can provide assistance to government decision makers. Operations research offers a variety of methods and algorithms that can be used to solve the earthquake disaster shelter location-allocation problem. The purpose of this paper is to develop and compare the usage of a genetic algorithm (GA) and modified particle swarm optimiszation (MPSO) in solving the disaster shelter location and population allocation problem. Thus, the research reported can provide evidence and guidance in terms of how future work may be directed in developing a hybrid method, i.e. one which intelligently uses a GA and MPSO in combination to determine better solutions than is possible if each method were used independently.

The remainder of this paper is organised as follows. An overview of related work is presented followed by the mathematical model of the disaster shelter location and population allocation problem allied with two solution methods, namely a GA and MPSO. To aid the description of the solution methods, an overview of the case study used in this research is given. Next, some preliminary results using the GA and MPSO are presented, along with a comparison of their differences, based on real communities and candidate shelters data. Finally, the paper is concluded and an indication of the direction of future work is given.

RELATED WORK

In relation to construction schemes of disaster shelters, there are different approaches that can be used to select sites such as spatial analysis of geographical information systems (Gall, 2004; Yamada et al., 2004; Sanyal et al., 2009) and mathematical models. According to the particular optimization objectives of shelter site selection, mathematical models can be divided into single-objective models (Sherali et al., 1991; Berman et al., 2002; Dalal et al., 2007; Gama et al., 2013; Bayram et al., 2015; Kılcı et al., 2015), hierarchical models (Chang et al., 2007; Liu et al., 2009; Li et al., 2012 Li et al., 2011;), and multi-objective models (Huang et al., 2006; Doerner et al., 2009; Alçada Almeida et al., 2009; Saadatseresht et al., 2009; Barzinpour et al., 2014; Rodríguez-Espíndola et al., 2015). Optimization methods, such as GAs, PSO, and simulation annealing (SA), can be used to solve these mathematical models as most of them are NP-hard problems (Leeuwen et al., 1998) that cannot be solved using traditional methods such as linear programming (Schrijver, 1998). GAs have been used successfully to solve the shelter location selection problem. For example, Kongsomsaksakul et al. (2005) applied a GA to the flood shelter location selection problem with transportation problem, which is a hierarchical model. Also, Doener et al. (2009) and Hu et al. (2014) proposed their GAs to solve multi-objective models of hurricane and disaster shelter site selection problems respectively. As one of the most popular algorithms, PSO is viewed as being simpler than other algorithms as it has fewer parameters and has a simulation process that is easier to understand leading to its application in many fields (Jin et al., 2007; Shen et al., 2007; Yin et al., 2007; Ai et al., 2009). Furthermore, PSO has attracted the attention of researchers in using it to solve the shelter site selection problem (Hu et al., 2012). While research has been carried out using different optimization techniques and investigating how these perform, there remains a need to analyse and compare the performance of different algorithms in order to establish their advantages and disadvantages and how they can be combined as a hybrid algorithm capable of determining improved solutions to the disaster shelter location and population allocation problem.

MATHEMATICAL MODEL AND OPTIMIZATION METHODS

In this section, a mathematical model for the earthquake shelter location-allocation problem is developed. Furthermore, two optimization heuristic algorithms, used to solve the aforementioned problem, are described. To aid the description of the optimization heuristic algorithms, an overview of the case study considered in this research is presented.

Mathematical model

Many types of models have been proposed to solve the shelter site selection problems, such as the P-median model (Bayram et al., 2015; Gama et al., 2015), the P-center model (Kılcı et al., 2015), the covering model (Dala et al. 2007; Gama, 2013), the hierarchical model (Widener, 2009; Widener, 2011) and the multi-objective model（Rodríguez-Espíndola and Gaytán, 2015). In the preliminary study reported in this paper, a multi-objective model has been selected; the same as proposed by Zhao et al. (2015). The two objectives are minimising total shelter area (TSA) (see equation (1)) and minimising total weighted evacuation time (TWET) (see equation (2)) subject to a capacity constraint (CC) (see equation (3)) and a time constraint (see equation (4)). Equation (5) expresses that a community can be allocated to only one shelter.

$$f_1 = \min \sum_{k=1}^{N} Y_k \times S_k \qquad \forall k = 1,2,\ldots\ldots,N \tag{1}$$

$$f_2 = \min \sum_{j=1}^{M} \sum_{k=1}^{N} \frac{d_{jk}}{v_j} \times \frac{P_j}{W_{jk}} \times B_{jk} \qquad \forall k = 1,2,\ldots\ldots,N \quad \forall j = 1,2,\ldots\ldots,M \tag{2}$$

$$\sum_{j=1}^{M} P_j L B_{jk} - S_k Y_k \le 0 \qquad \forall k = 1, 2, \ldots\ldots, N \tag{3}$$

$$d_{jk} B_{jk} - D_j \le 0 \qquad \forall k = 1, 2, \ldots\ldots, N \quad \forall j = 1, 2, \ldots\ldots, M \tag{4}$$

$$\sum_{k=1}^{N} B_{jk} Y_k = 1 \qquad \forall j = 1, 2, \ldots\ldots, M \tag{5}$$

where N is the total number of candidate shelters, Y_k indicates if candidate shelter k is allocated as a shelter (1 if allocated, 0 if not allocated), S_k is the area of candidate shelter k, M is the total number of communities, d_{jk} is the length of the shortest path between community j and candidate shelter k, and v_j is the evacuation speed of the people in community j calculated as:

$$v_j = (2 \times p_c \times v_c + (p_a - p_c) \times v_a + p_o \times v_o) \times \rho \tag{6}$$

where v_c, v_a and v_o represent the speed of a community's children, adults and elderly people as defined by Gates (2006), and p_c, p_a, and p_o are the proportions of the different categories of people respectively, and ρ is an adjustment parameter of the evacuation speed relative to the ordinary speed (set to 1 in this study). Furthermore, P_j is the number of people to be evacuated in community j, W_{jk} is the mean width of the evacuation path from community j to candidate shelter k, B_{jk} indicates if candidate shelter k is allocated to community j (1 if allocated, 0 if not allocated; note that all people within a particular community are allocated to the same shelter), L is the smallest refuge area per capita (1 m^2/person (Beijing Municipal Institute of City Planning & Design, 2007)), and D_j is the maximum evacuation distance for the people in community j, which is equal to the product of $Tmax_j$ and v_j, with $Tmax_j$ being the maximum evacuation time for community j.

Case study

Figure 1 indicates the location of the geographical area considered in the study presented in this paper, namely Jinzhan, Chaoyang, Beijing, China. More specifically, Figure 1(a) shows the location of Beijing in China and Figure 1(b) shows the location of Jinzhan within Chaoyang in Beijing.

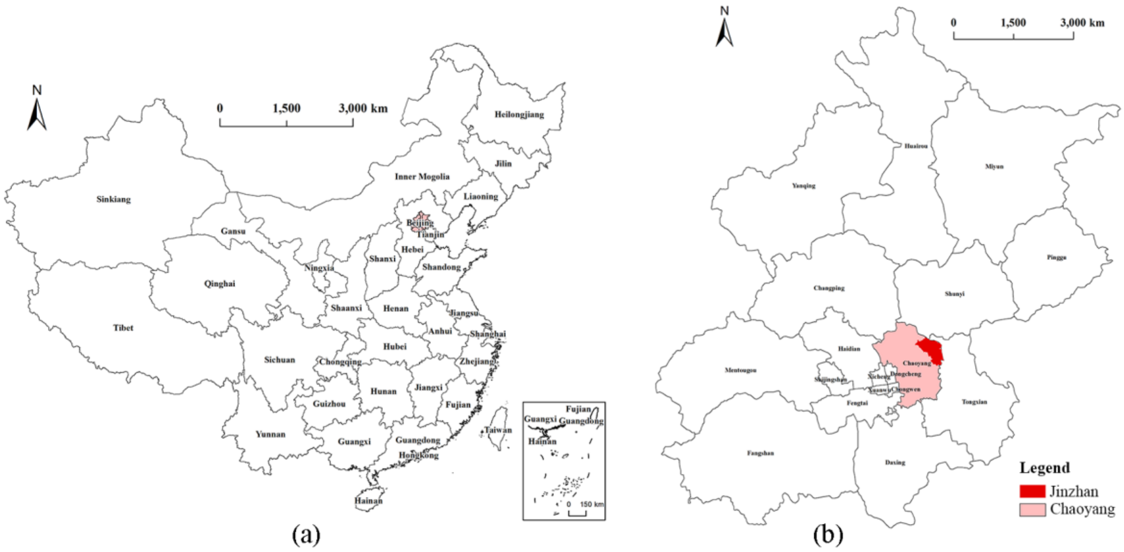

Figure 1. Location of Jinzhan, Chaoyang, Beijing, China

Figure 2(a) presents a map of communities, shelters and evacuation path network, which was provided by the Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education, Beijing Normal University. Furthermore, Figure 2(a) indicates the locations of 10 candidate shelters and 15 communities that need to be allocated to the selected shelters. The locations of candidate shelters were determined in consideration of the requirement that these should be at least a distance of 500m from the earthquake faults (Hu et al., 2014). In the model presented in this paper, it is assumed that sheltering assets are able to be delivered to those shelters selected when solving the location-allocation problem. Figure 2(b) shows population data which was provided by the Beijing Bureau of Civil Affairs. Table 1 indicates the area of each of the 10 candidate shelters, the number of people in each of the 15 communities and the distance between communities and shelters.

Figure 2. Location of communities, shelters, evacuation paths and distribution of population

Table 1. Area of candidate shelters, population of community and distance between communities and candidate shelters

		Candidate shelter index									
		1	2	3	4	5	6	7	8	9	10
	Area(m^2) / Population	803385	502342	203617	1114636	232884	236840	741967	157105	357538	112152
Community index 1	3848	10575.4	2920.6	4410.4	3397.1	1565.1	2351.1	3687.6	3691.3	8080.5	1981.5
2	1650	1411.0	8488.5	7679.4	9096.8	9489.1	10647.4	11320.5	6626.0	4438.1	11370.7
3	956	1392.9	9112.8	8303.7	8965.4	9885.3	11075.8	11944.8	7250.3	2703.3	11799.1
4	5874	3492.6	7451.5	6642.4	8149.5	8452.1	9610.4	10283.4	5589.0	5841.1	10333.7
5	2157	5600.8	3583.2	2774.1	4455.3	4583.8	5742.1	6415.2	1540.3	5142.3	6465.4
6	10937	6170.0	5173.8	5733.4	4966.2	5886.1	7076.7	8004.3	3676.7	3147.5	7800.0
7	4251	8158.2	3875.9	4672.0	1576.7	2821.8	4012.3	5271.3	2565.4	5135.7	4735.6
8	12858	5375.1	8509.0	8690.2	8082.5	9002.4	10193.0	11339.5	7011.9	2575.6	10916.3
9	868	7501.7	1771.6	2125.1	3275.6	2772.2	3930.5	4603.5	360.6	5389.5	4653.8
10	2716	9820.4	1167.3	3151.2	3341.2	2074.2	1989.5	2270.7	2936.2	7491.3	2773.2
11	1276	8902.9	1329.4	2814.2	2856.1	1589.1	2539.8	3053.7	2018.7	6573.8	3264.3
12	3452	8376.2	627.4	1929.2	3598.1	2664.4	3168.2	3459.3	1492.1	6169.6	3945.5
13	455	1949.2	7778.8	6969.6	8476.7	8779.4	9937.7	10610.7	5916.2	4976.3	10661.0
14	2084	10581.3	2235.9	4246.3	3435.2	1753.1	1552.8	2918.4	3697.2	8118.6	2104.7
15	4618	4801.5	6798.6	6851.1	6540.3	7460.2	8650.8	9629.1	5231.5	736.5	9374.1

Optimization heuristics

Different approaches can be taken to solve optimization problems involving multiple objectives such as that considered in this paper, i.e. minimising total shelter area (TSA) and minimising total weighted evacuation time (TWET). One approach is to convert the multi-objective problem into a single objective problem. This can be achieved by summing the weighted values of each of the multiple objectives to give a single value. However, the weight assigned to each objective can be difficult to set due to the lack of prior information on the relative importance of each one. Thus, this approach can involve performing a sensitivity analysis in which the weights assigned to each of the multiple objectives are varied. An alternative approach, referred to as Pareto-based (Pareto, 1896), involves a set of optimal solutions in which, for each solution, no increase can be achieved in any of the objectives without resulting in a simultaneous decrease in at least one of the remaining objectives.

In the preliminary work reported in this paper, both approaches have been used and compared. For the weight-based approach, the objective function, to be minimised, is defined as the sum of the weighted objective value of TSA and TWET,

$$f = (\alpha \times TSA) + (\beta \times TWET) \tag{7}$$

where α and β are the weight of TSA and TWET respectively. These weights represent the relative importance of each objective and, thus, each varies between 0 and 1 and they sum to unity.

For the Pareto-based approach, any feasible solution which is non-dominated in terms of the two objectives, i.e. TSA and TWET, is defined as a solution in the Pareto optimal set.

In this paper, MPSO, which is assisted by a SA algorithm during the search for local optima, and a GA have been used to solve the earthquake shelter location-allocation problem. Flowcharts of the MPSO and GA are shown in Figure 3(a) and 3(b) respectively.

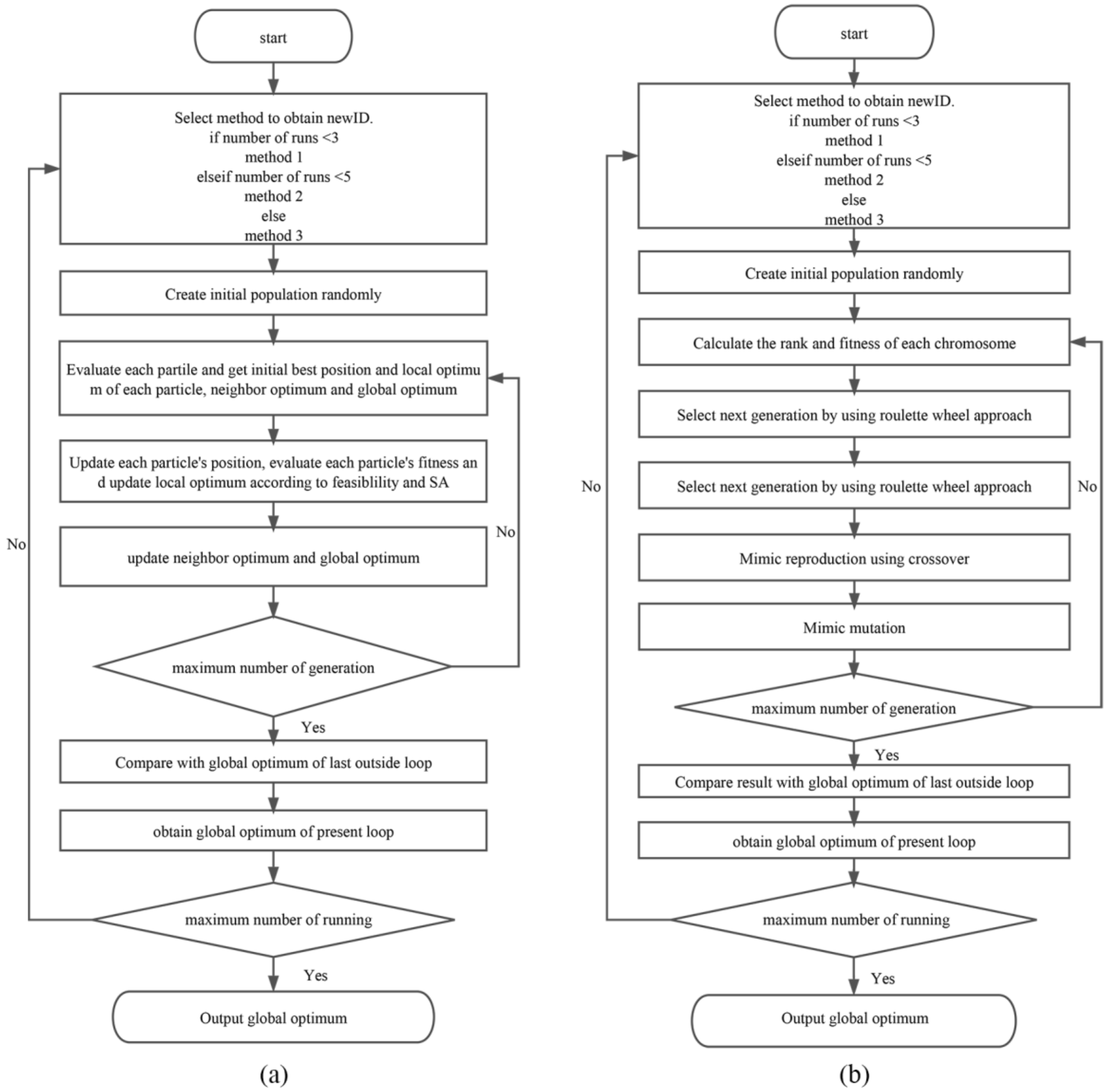

Figure 3. Flowcharts of (a) MPSO and (b) GA

Although the MPSO and GA are different in many aspects, both need to generate an initial population, which traditionally is done randomly. In order to investigate the effect of the initial population on the final 'optimized' solutions obtained, three different methods have been used to account for the indexing of the ten shelters to which the fifteen communities must be allocated. All three methods involve allocating each community, in turn, to one of the ten candidate shelters providing each allocation does not violate the capacity constraint or time constraint referred to in relation to equations (3) and (4) respectively. That is, not all communities can be allocated to every shelter. The number of shelters to which a community can be allocated is summarized in the vector {8, 2, 2, 2, 8, 5, 9, 2, 9, 8, 8, 8, 2, 8, 3}, where, for example, community 1 can be allocated to only 8 of the 10 shelters, community 2 can be allocated to only 2 shelters and so on. Method 1 assigns indices to candidate shelters, to which a community can be allocated, according to those indicated in Figure 2, then as communities are allocated to shelters these indices are reset from 1 to the number of remaining potential shelters to which a community can be allocated. Method 2 assigns indices to candidate shelters according to the time for a community to reach the possible candidate shelters such that the nearest shelter to the community is given an index of 1, the next nearest shelter to the community is given an index of 2 and so on. As each community is allocated to a candidate shelter, indices are reset from 1 to the number of remaining potential shelters to which a community can be allocated. Method 3 assigns indices to candidate shelters according to the area of each possible candidate shelter to which a community can be allocated such that the candidate shelter with the smallest area capable of housing the community is assigned an index 1 and so on. Again, as each community is allocated to a candidate shelter, indices are reset from 1 to the number of remaining potential shelters to which a community can be allocated. As an example, taking community 1 which can be allocated to only 8 of the 10 shelters, namely {2, 3, 4, 5, 6, 7, 8, 10}, the indices set according to the three methods are shown in Table 2.

Table 2. Community 1's candidate shelter indices set according to the three methods

	Candidate shelter indices							
Original	2	3	4	5	6	7	8	10
Method 1	1	2	3	4	5	6	7	8
Method 2	6	7	5	3	2	8	1	4
Method 3	6	3	8	4	5	7	2	1

The MPSO algorithm used has been described as detailed in the work of Zhao et al. (2015). In the GA that has been developed, each solution's chromosome, which corresponds to a location and allocation plan, consists of fifteen genes, one per community, $\{g_1, g_2, g_3, \ldots, g_{15}\}$ with each gene represented as a binary number with four digits. For example, a chromosome could be represented as follows by using Method 1,

{0011, 0001, 0010, 0001, 1000, 0100, 0010, 0001, 0100, 1000, 0001, 0011, 0001, 0111, 0010}.

In this example, the indices of candidate shelters selected to allocate each community are {3, 1, 2, 1, 8, 4, 2, 1, 4, 8, 1, 3, 1, 7, 2}. Thus, the original indices can be obtained using Table 2, which indicates that community 1 is allocated to candidate shelter 4, community 2 is allocated to candidate shelter 1, and so on.

At each generation, for each solution's chromosome, the TSA and TWET objective values are calculated. For example, consider the five solutions' chromosomes, C_1 to C_5, generated, say, using Method 1,

C_1 = {0111, 0001, 0001, 0010, 0110, 0100, 0111, 0001, 0100, 1000, 0101, 0111, 0001, 0101, 0010}

C_2 = {0111, 0010, 0010, 0010, 0001, 0101, 0101, 0010, 0111, 0111, 0010, 0100, 0010, 1000, 0011}

C_3 = {0101, 0001, 0001, 0010, 0111, 0100, 1000, 0001, 0101, 0101, 0111, 0110, 0001, 0110, 0011}

C_4 = {0100, 0010, 0001, 0001, 0111, 0101, 1001, 0010, 0001, 0101, 1000, 0101, 0010, 0001, 0011}

C_5 = {0101, 0010, 0001, 0010, 0010, 0100, 0111, 0010, 0010, 0101, 0100, 0010, 0010, 0101, 0001}

In C_1, community 1 is allocated to candidate shelter 8 (using the mapping given in Table 2), communities 2 and 3 are both allocated to candidate shelter 1 since it is capable of housing both communities (using a mapping not given in this paper), and so on. For the five solutions' chromosomes shown, the TSA and TWET objective values are (1542368, 10688895.5), (2103524, 8954749.6), (2296837, 10443330.5), (2402250, 9527582.7) and (2493715, 9921918.0) respectively. These values of TSA and TWET are obtained using equation 1 and 2 respectively, along with the data presented in Table 1. Based on these values, each solution is ranked according to how many other solutions in the population dominate it. That is, if a solution is non-dominated, i.e. no other solution has 'better' (lower) values for both TSA and TWET objectives, then it is ranked 1 as it is Pareto-optimal. From the five example chromosomes shown, it can be seen that C_1 and C_2 are non-dominated so have rank R = 1, C_3 and C_4 are dominated by C_2 so have rank R = 2, and C_5 is dominated by C_2 and C_4 so has rank R = 3. Based on these ranks, the fitness of each solution is calculated according to a fitness function

$$F_i = (n + 1 - R_i)^{\gamma} \tag{8}$$

where n is the number of solutions in a population and γ is a coefficient set to unity in this work. Again referring to the five example chromosomes shown, the fitness values are 5, 5, 4, 4 and 3 respectively. Based on fitness values, the next generation is obtained via a roulette wheel approach in which fitter solutions are more likely to be selected. Also, within the GA, crossover and mutation are used. In relation to the crossover operation, based on chromosomes being selected according to a crossover probability, single point crossover has been selected for use after it was shown, in the problem domain considered in this paper, to outperform two-point crossover and bitwise crossover. The mutation operation, using a mutation probability, involves probabilistically selecting chromosomes for mutation then randomly selecting genes in which the four digit binary number is altered. A sensitivity analysis revealed that for the earthquake shelter location-allocation problem under consideration, better optimized solutions were obtained using a crossover and mutation probability of 0.84 and 0.009 respectively.

PRELIMINARY RESULTS AND DISCUSSION

This section presents comparisons of the performance of MPSO and GA, using the three methods to set the indices of candidate shelters to which the fifteen communities must be allocated. Furthermore, these comparisons are considered using a Pareto-based approach and then the weight-based approach (converting the multi-objective problem into a single objective problem) as described in the previous section. In all runs of the MPSO and GA, the population size and number of generations were both set to 100.

Pareto-based approach

Figure 4 shows the Pareto solutions obtained by the GA (Figure 4(a)) and MPSO (Figure 4(b)) using the three methods to set the indices of candidate shelters. In Figure 4(a), using the GA, it can be observed that the three methods result in noticeably different sets of Pareto solutions. Furthermore, the majority of the non-dominated solutions were obtained using Method 2; however one non-dominated solution, with lower TSA, stems from Method 3. As shown in Figure 4(b), for MPSO, the spread of Pareto solutions is similar using Methods 2 and 3, although it is observed that all non-dominated solutions were obtained via Method 2.

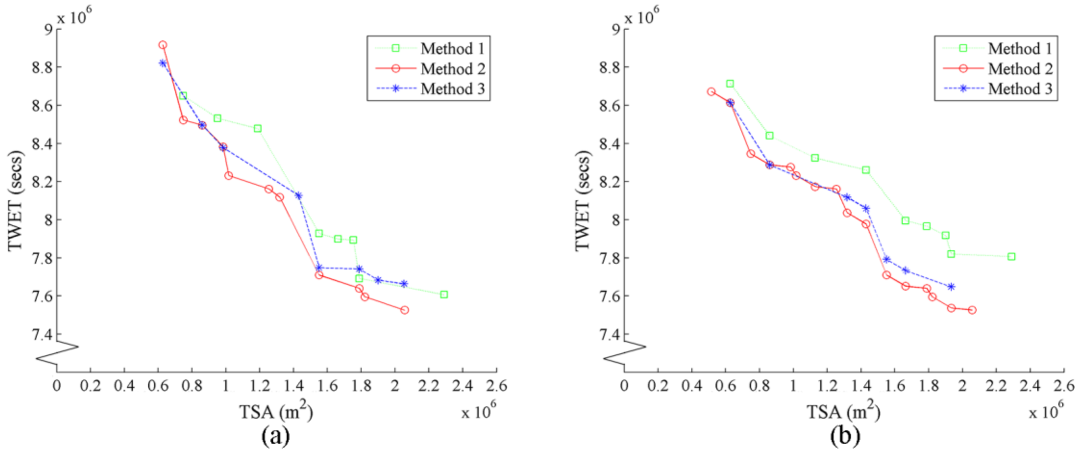

Figure 4. Pareto solutions obtained via the methods for setting candidate shelter indices using (a) GA and (b) MPSO

Figure 5 presents a direct comparison between the results obtained using the GA and MPSO with each of the three methods to set the indices of candidate shelters. In Figure 5(a), using Method 1, it can be seen that MPSO and the GA perform better than each other in different regions of the search space. In contrast, MPSO performs better than the GA using Methods 2 and 3 as shown in Figures 5(b) and 5(c) respectively.

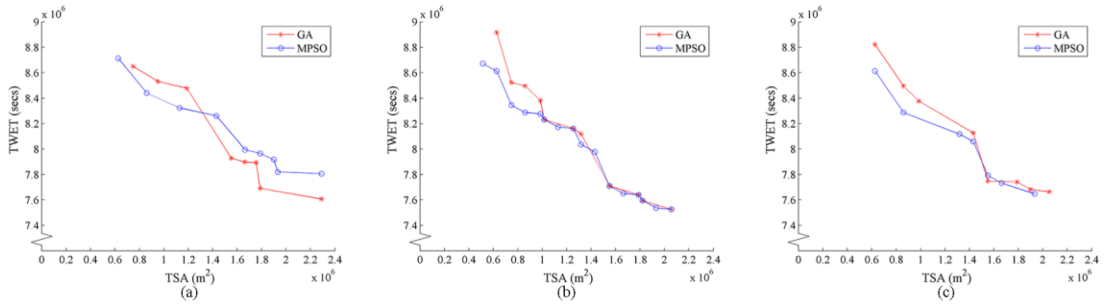

Figure 5. Pareto solutions obtained by the GA and MPSO using (a) Method 1, (b) Method 2 and (c) Method 3

Based on multiple runs using all three methods, Figure 6(a) presents the 'best' Pareto solutions obtained from the GA and MPSO in solving the specific location-allocation problem considered in this paper. In this figure it is apparent that the Pareto solutions generated by MPSO are better than those generated by the GA. Taking the solutions at various locations on the Pareto front marked ‘A’, ‘B’, and ‘C’ in Figure 6(a) as examples, Figure 6(b), (c) and (d) show the location of the candidate shelters selected and an indications of how the fifteen communities are allocated to them. It is noted that for the three Pareto solutions highlighted, different numbers of shelters are selected for the fifteen communities to be allocated. Specifically, Pareto solutions ‘A’, ‘B’ and ‘C’ utilize five (numbered 1, 2, 6, 8, 9), three (numbered 1, 8, 9) and two (numbered 8, 9) candidate shelters respectively. It is observed that for all three Pareto solutions highlighted, candidate shelters 8 and 9 are always utilized. Indeed, for Pareto solution ‘C’, which corresponds with a low value of TSA and high value of TWET, only candidate shelters 8 and 9 are utilized. However, for Pareto solution ‘B’, with a greater value of TSA and lower value of TWET, candidate shelter 1 is also utilized. Also, for Pareto solution ‘A’, with a high value of TSA and low value of TWET, candidate shelters 2 and 6 are utilized in addition to 1, 8 and 9. Another observation for all three Pareto solutions highlighted is that communities 1, 5, 6, 7, 9 and 11 are always allocated to candidate shelter 8 while communities 8 and 15 are always allocated to candidate shelter 9.

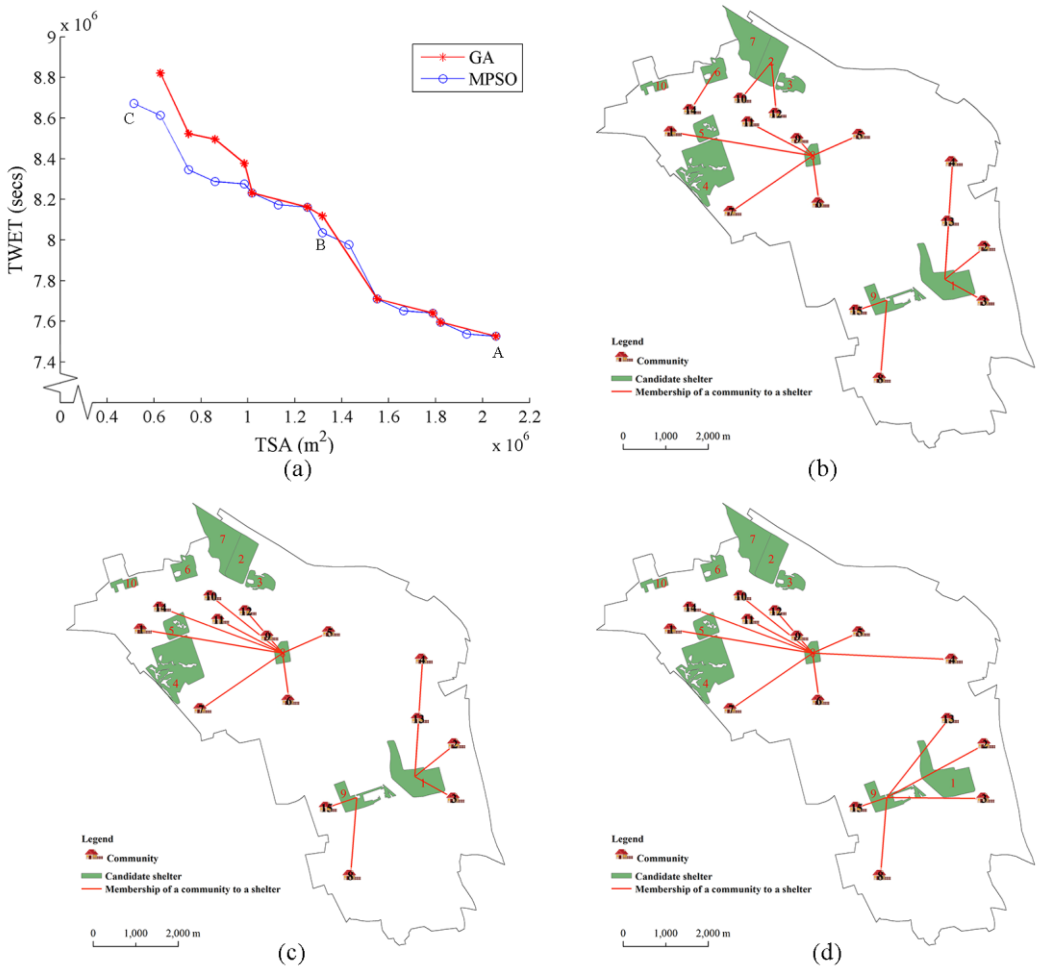

Figure 6. (a) ‘Best’ Pareto solutions obtained using the GA and MPSO and (b) (c) and (d) illustrate the Pareto ‘location-allocation’ solutions corresponding to point A, B and C respectively

The utilized and non-utilized shelter areas associated with the Pareto solutions obtained are presented in Figure 7(a) and (b) for the GA and Figure 7(c) and (d) for MPSO. It can be seen that utilized areas of the selected shelters are significantly less than the non-utilized areas. Thus, each selected shelter has sufficient room to house relief workers and volunteers, along with relief assets, and for the evacuees to move around.

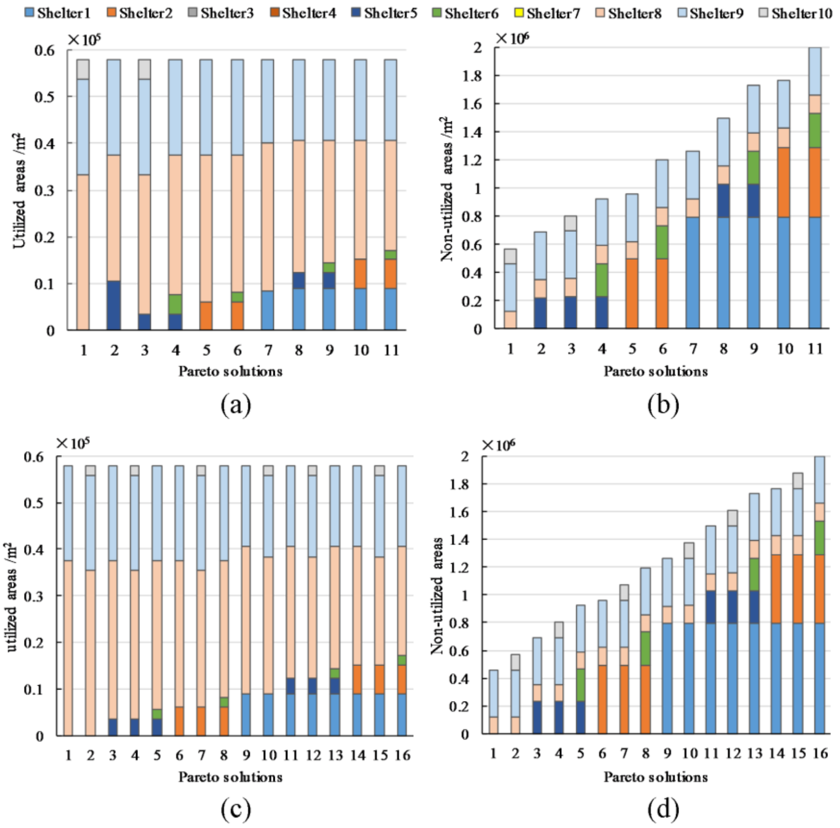

Figure 7. Utilized and non-utilized shelter areas associated with the Pareto solutions for the GA (see (a) and (b)) and MPSO (see (c) and (d))

Weight-based approach

In converting the multi-objective problem to a single objective problem, weights of 0.5 were assigned to α and β. Thus, equation (7) to evaluate the objective function, to be minimized, can be written as

$$f = (0.5 \times TSA) + (0.5 \times TWET) \tag{9}$$

Figure 8 presents the convergence of the objective function using the GA (Figure 8(a)) and PSO (Figure 8(b)) with the three methods to set the indices of candidate shelters. In Figure 8(a), for the GA, it can be observed that using Method 1 results in better solution being found than the other two methods. In addition, convergence using Methods 1 and 2 is similar, both being quicker than Method 3. For MPSO, Figure 8(b) shows that Method 2 leads to better solution than the other two methods. Also, Methods 2 and 3 show similar convergence, both doing so more quickly than Method 1.

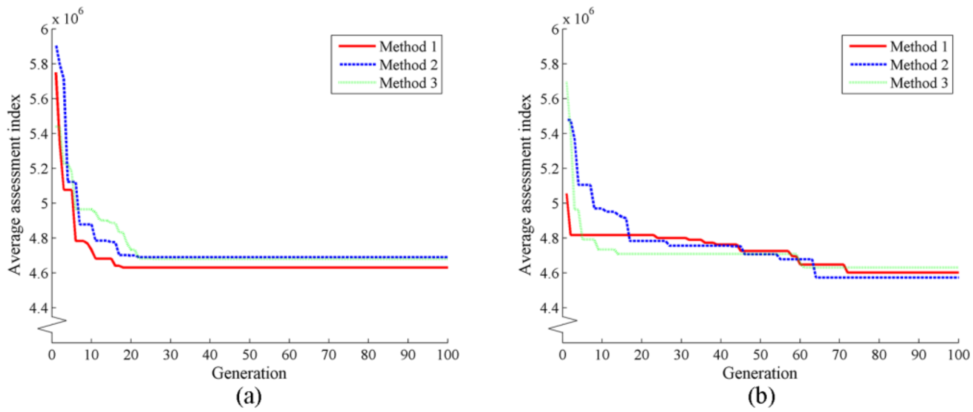

Figure 8. Convergence of objective function obtained via the methods for setting candidate shelter indices using (a)

GA and (b) MPSO

Figure 9 presents a direct comparison of the results obtained using MPSO and GA with each of the three methods to set the indices of candidate shelters. In Figure 9(a) it can be seen that using Method 1, the GA outperforms MPSO for the majority of generations (approximately 70). However, beyond approximately 70 generations, the MPSO yields better solutions than the GA. Similar observations can be made using Methods 2 and 3 as shown in Figures 9(b) and 9(c) respectively. The best solution generated by the GA and MPSO, in terms of the location of the candidate shelters selected and how the fifteen communities are allocated to them, are shown as Figure 10(a) and Figure 10(b) respectively.

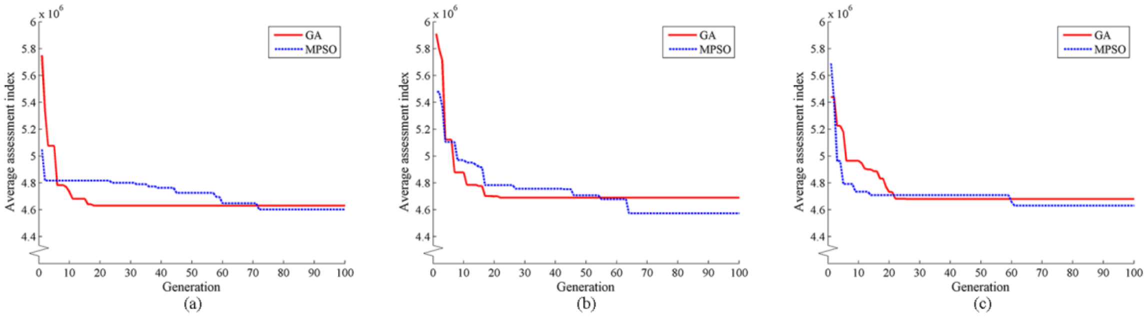

Figure 9. Convergence of objective function with the GA and MPSO using method 1 (a), 2 (b) and 3 (c)

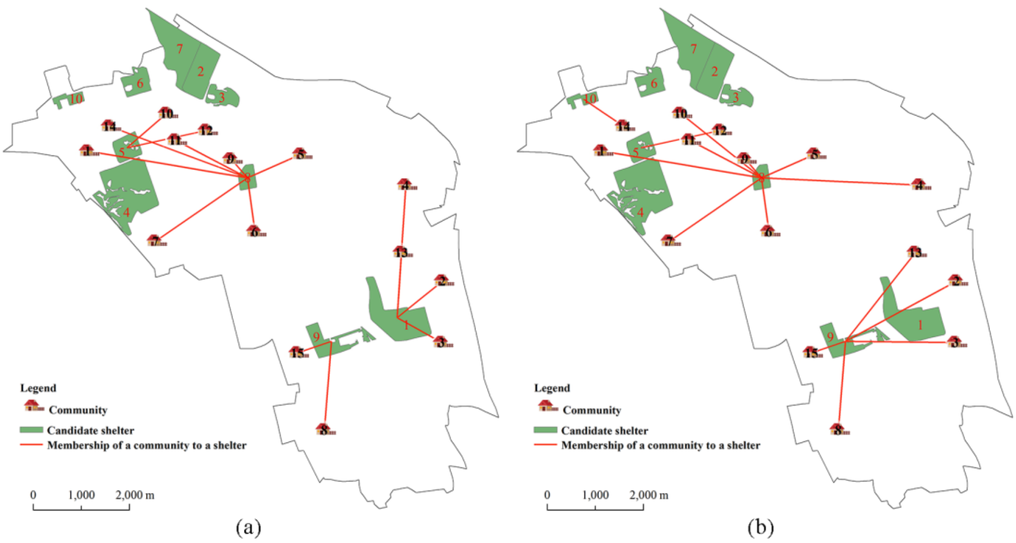

Figure 10. Best 'allocation-location' solutions generated using the (a) GA and (b) MPSO

Comparison of approaches

The Pareto-based and weight-based approaches offer two different ways of solving the multi-objective problem described in this paper. The Pareto-based approach yields a set of 'best' (non-dominated) solutions, whereas the weight-based approach produces a single 'best' solution which depends on the weights assigned to each of the multiple objectives. Consequently, it is not possible to compare the 'best' solutions obtained using the two approaches. However, it is possible to consider an example Pareto solution and compare this with the 'best' solution produced via the weight-based approach (with both weights set at 0.5). For example, compare the Pareto solution marked 'B' in Figure 6(a), which is also illustrated in terms of the location of the candidate shelters selected and how the communities are allocated to them in Figure 6(c), and the MPSO's weight-based solution shown in Figure 10(b). The Pareto solution utilized candidate shelters 1, 8 and 9 with a TSA of 1318028 m^2 (determined from Table 1) and TWET of 8035780 seconds. In contrast, the 'best' solution via the weight-based approach utilized candidate shelters 5, 8, 9 and 10 with a TSA of 859679 m^2 and TWET of 8287234 seconds. As such, the 'best' solution via the weight-based approach is not dominated by the Pareto solution.

CONCLUSION

The aim of this paper was to present preliminary work in evaluating the performance of two optimization heuristics, namely a GA and MPSO, in solving the earthquake disaster shelter location-allocation problem considered. This preliminary work will support the direction of future work regarding how a hybrid optimization algorithm, using a GA and MPSO in combination, can be developed to improve solutions to the earthquake shelter location and allocation problem, which will inform disaster management strategies.

In this paper, a comparison has been undertaken of the performance of a GA and MPSO, using three different methods to determine the initial population, according to a Pareto-based approach and a weight-based approach. It was found that all three methods mentioned have advantages and disadvantages and thus it is proposed that an appropriate direction of the next stage of our research is to combine their use. However, when the weighted method is used, the convergence process is clear, which highlights that MPSO is better in the early and final stages of the optimization process; in contrast the GA performs better than MPSO over the majority of generations between the early and final stages of the optimization process. Although a GA and MPSO have been compared and the results give some information regarding how to combine them to obtain better optimized solutions more quickly, the simple GA developed to date requires further work to include aspects such as niching and elitism. Also, in terms of further work, a number of improvements will be made to the mathematical model. For example, damage to the shelters and evacuation roads caused by an earthquake will be considered. In addition, the possibility of evacuees belonging to the same community being divided and allocated to multiple shelters will be considered. Finally, results generated from this research will be presented to practitioners involved in managing earthquake disasters, which is viewed as an important aspect of this work.

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Agent-based Modelling and Simulation for Lecture Theatre Emergency Evacuation

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ABSTRACT

This paper presents an overview of ongoing research into the implementation of an agent-based model aimed at providing decision support for the layout design of lecture theatres and human behavioural management in emergency evacuation. The model enables the spatial layout of lecture theatres to be configured and incorporates agent behaviours at the basic movement and individual level. In terms of individual behaviours, agents can be competitive, cooperative, climb obstacles (e.g. seating and desks) and fall down. Two cases are investigated to evaluate the effects of different exit locations in lecture theatres and competitive behaviour of agents on evacuation efficiency in multiple scenarios.

Keywords

Emergency evacuation, agent-based modelling and simulation

INTRODUCTION

Emergency situations in which evacuation is necessary can occur in locations with highly dense crowds of people, which may lead to serious casualties and even fatalities. There are many reported events in which emergency egress has resulted in injuries to people and loss of lives. For example, 8 students were killed and another 26 were injured in a stampede in a school stairwell in Hunan province, central China (BBC News, 2009). In this incident, about 400 students made for one narrow stairway after evening classes when one fell, setting off the crush. Therefore, emergency evacuation is particularly crucial in emergency and safety management, and in locations with a capacity for high occupancy.

Preparing and performing field emergency evacuation experiments can be expensive and time consuming with the consequence that only a few scenarios are able to be considered. Computer simulation is a cost-effective and safe means to assess egress performance with the ability to consider multiple 'what-if' scenarios (Chu et al., 2013; Wagner and Agrawal, 2013). Furthermore, complex human behaviour is difficult to model in emergency evacuation situations. Agent-based simulation has been used to study crowd evacuation in various situations due to its ability to replicate and assess human behaviour in evacuation scenarios (Fang et al., 2016; Tan et al., 2014; Chu et al., 2013; Pan et al., 2006; Wagner and Agrawal, 2014; Wang et al., 2015; Sun and Li, 2013; Xie et al., 2016). Although agent-based modelling and simulation has been used in current research, there is still a lack of realistic human behaviours modelled.

The ongoing research reported in this paper aims to develop an agent-based modelling and simulation system, which provides decision support for both the layout design of lecture theatres and human behavioural management in emergency evacuation. In terms of novel contribution, the ongoing research provides an agent-based model that is specifically designed for evacuation modelling from lecture theatres in which a number of internal obstacles (desks and seats) are located along with a high density of students. Furthermore, the integrated framework being developed and implemented incorporates realistic human behaviour and enables layout design.

RELATED WORK

A number of evacuation simulation models has been proposed (Bouzat and Kuperman, 2014; Chu et al., 2013; Ehtamo et al., 2010; Fang et al., 2016; Joo et al., 2013; Lu et al., 2016; Mesmer and Bloebaum, 2014; Pan, 2006; Song et al., 2016; Sun and Li, 2013; Tan et al., 2014; Wagner and Agrawal, 2014; Wang et al., 2015; Zheng and Cheng, 2011; Xie et al., 2016; Xie and Xue, 2011). According to the hierarchical layers of agent behaviour in evacuation models, these models can be classified into four categories, namely basic movements, individual behaviour, group behaviour and crowd behaviour.

The first category of models focus primarily on basic evacuation movements such as collision avoidance, exit detection and exit seeking. The bulk of published models fall within this category and often make assumptions and simplifications about agent behaviours such as simplifying the evacuation process into the movement of occupants from their initial positions to the outside of the building without considering behaviours such as competitive behaviour that may delay evacuation (Kuligowski, 2008). An affordance-based model assumes that the agent-based simulation framework considers only perception-based action, which implies the ecological properties of affordance and effectivity, rather than the social factors that might affect decision making (Joo et al., 2013). Two models mainly concentrate on the spatial aspect of evacuation while high level behaviours are not taken into account (Wagner and Agrawal, 2014; Tan et al., 2014). Wagner and Agrawal present an agent-based simulation system for crowd evacuation of concert venues under a fire disaster, which allows for user definition of the layout and structure of the concert venue (Wagner and Agrawal, 2014). Tan et al. develop a grid graph-based model where potential escape routes from each node could be analyzed through GIS functions of network analysis considering both the spatial structure and route capacity (Tan et al., 2014).

Individual behaviours are usually developed in models according to personal state such as (1) competitive (also referred to as impatient (Heliövaara et al., 2013), defect (Bouzat and Kuperman, 2013) and cooperative (also known as patient (Heliövaara et al., 2013) or yielding (Xie and Xue, 2011)) behaviour depending on stress level (Pan 2006, Fang et al. 2016) or bounded rationality (Heliövaara et al., 2013; Zheng and Chen, 2011, Bouzat and Kuperman, 2014; Song et al. 2016; Xie and Xue, 2011) or panic (Wang et al., 2015) and (2) exit choice where herding behaviour occurs based on degree of uncertainty (Pan, 2006) or exit choice relying on bounded rationality (Ehtamo et al., 2009; Mesmer and Bloebaum, 2014). In evacuation modelling, based on game theory, a number of researchers assume that agents evaluate all the available options and select the one with maximum utility (Ehtamo et al., 2009; Heliövaara et al., 2013; Mesmer and Bloebaum, 2014; Zheng and Chen, 2011, Bouzat and Kuperman, 2013; Song et al. 2016; Xie and Xue, 2011). For example, Ehtamo et al. assume that agents update their game strategies of exit choice based on their best response functions in a myopic manner (Ehtamo et al., 2009). Mesmer and Bloebaum develop a unique utility function based on energy expenditure for game strategies of exit alternative selection (Mesmer and Bloebaum, 2014). Four models make an assumption that each agent has two possible game strategies of play that lead to competitive and cooperative behaviour and agents adopt the strategy that would give them the highest payoff (Heliövaara et al., 2013; Zheng and Chen, 2011, Bouzat and Kuperman, 2013; Xie and Xue, 2011). Song et al. present game strategies for pedestrians combined with analyzing the reasons why agents choose to be competitive or cooperate combining with human emotions such as sympathy. Other researchers suppose that agents will behave in a competitive or cooperative manner given their level of mental stress (Pan, 2006, Fang et al. 2016) or panic state (Wang et al., 2015). Herding behaviour principally resulted from uncertainty associated with having insufficient information regarding what to do, thus resulting in them tending to follow the actions of others (Pan, 2006).

Agent behaviours simplified to individual level without considering group influence lacks realism as in the real world most people prefer to associate themselves with others in small groups (Xie et al., 2016). Based on Fang's work, there are two kinds of groups, namely social groups established by pre-existing relationships and informal groups established by informal and temporary relationships (Fang et al., 2016). Fang et al. propose that both groups can have a leader; however the leader-follower model in informal groups is temporary. There are other models concentrating on the implementation of social group behaviour (Chu et al., 2013; Lu et al., 2016; Xie et al., 2016). Chu et al. develops three group behaviours, namely group leader following, group member following and group member seeking (Chu et al., 2013). Lu et al. and Xie et al. both agree that group behaviours include staying together with group members and backtracking to search for lost group members (Lu et al., 2016; Xie et al., 2016). Lu et al. assume that the group leader may stop with a probability to wait for the other group members to return within a period of time (Lu et al., 2016). Xie et al. suppose that it is more reasonable to go back to search instead of waiting at some fixed position (Xie et al., 2016). In addition, in Xie et al.'s model, agents stay closer to socially intimate group members instead of simply moving to the so-called "group center".

At crowd level, agent behaviours are usually influenced by crowd density and velocity around an agent. Chu et al. use a navigation crowd density parameter to define the maximum crowd density in which agents can choose to execute individual and group behaviours (Chu et al., 2013). When the surrounding crowd density exceeds the navigation crowd density, other agents would give access priority to the agent with higher social order (Drury et.

al., 2009) by allowing the individual agent to pass through; therefore the agent with higher social order can navigate a congested area more easily. Fang et al. develop besieger-in-crowd behaviour which means an agent stuck in a slow-moving dense crowd and following the agent directly in front cannot behave competitively (Fang et al. 2016).

PRELIMINARY AGENT-BASED MODEL

Overview

The agent-based model under development is specifically designed for lecture theatres in which a number of obstacles (desks and seats) are located along with a high-density of students. The layout of obstacles and behaviours of students in a lecture theatre may negatively contribute to evacuation efficiency. Therefore, when modelling emergency evacuation, it is especially important to take into account both spatial layout and agent behaviours. One aim of this research is to estimate the effect of the internal arrangement and layout of lecture theatres on evacuation efficiency. Multiple scenarios can be simulated (e.g., wider aisles, additional exits, and so on). Another aim of the research is to measure the effect of agent behaviours on evacuation efficiency. At the early stage of the research, agent behaviours have focused on basic movement and individual level. The individual agent behaviours discussed in this paper are competitive, cooperative, climbing and falling down. In addition, conflicts between agents caused by competitive behaviour are represented.

Spatial Layout of the Environment

The layout of a lecture theatre is constructed in a grid environment with each cell being capable of multi-occupancy (up to three agents). The spatial layout of lecture theatres includes desks, seats, aisles, a front area and a back area. Figure 1 presents an example of the spatial layout of a lecture theatre that has been used in the preliminary simulations. As shown in Figure 1, there are two exits represented by two abreast cells, two aisles, desks (coloured green) and seats (coloured yellow). Every cell of an exit is defined as an Exit Cell (EC) whereas every cell of an aisle is defined as an Aisle Cell (AC). Exits and aisles both can be defined by three parameters: quantity, width and location. In addition, the width of the front area and back area, number of rows and columns of desks and seats can be set by the user of the agent-based modelling and simulation system.

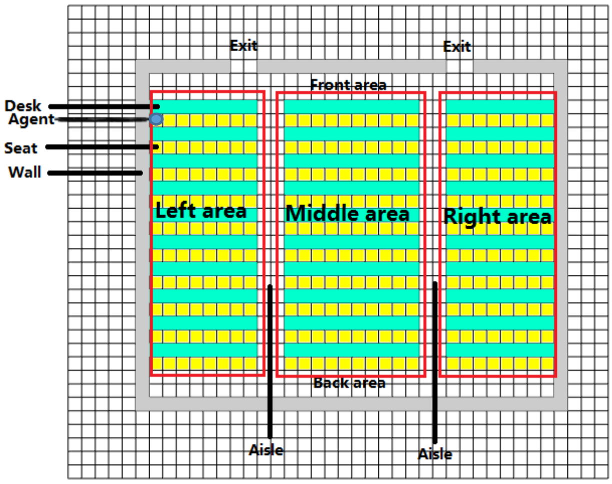
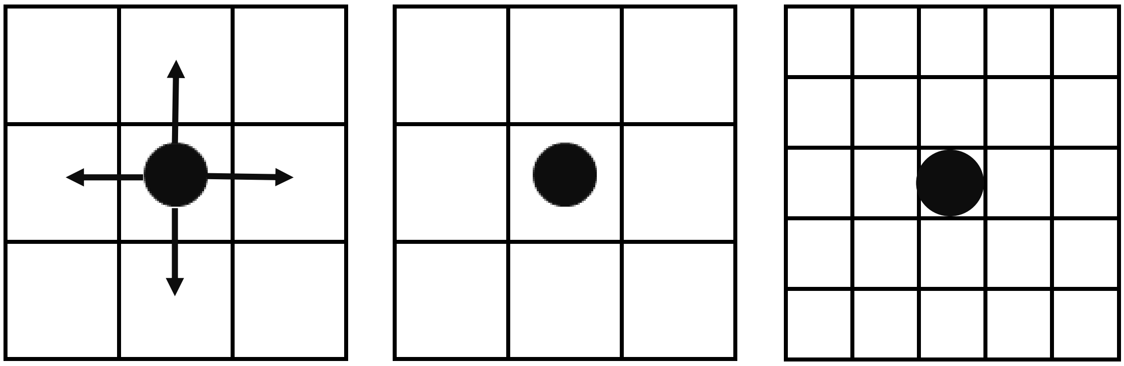


Figure 1. Example Layout of a Lecture Theatre

Agent Behaviour

Basic Movement

In the model, time and space are discrete and an agent can move one or two space steps (one space step means one cell) at every time step. Most studies on emergency evacuation in square lattices are based on either the von Neumann neighbourhood (VN) (Joo et al., 2013; Lu et al., 2016; Zheng and Cheng, 2011) or the Moore neighbourhood (MN) (Wang et al., 2015; Sun and Li, 2013; Heliövaara et al., 2013; Song et al., 2016). Figure 2(a) presents a VN where the agent located in the centre cell can move to its neighbouring 4 cells in a single time step. Figure 2(b) presents a MN where the agent located in the centre cell can move to its neighbouring 8 cells in a single time step. In real life dense crowds, the number of immediate neighbours is usually closer to 8 than to 4 (Heliövaara et al. 2013) and thus, the choice of the MN is viewed as a natural choice for the model presented in this paper when an agent moves one space step in a single time step. However, when an agent moves two space steps in a single time step, it can move beyond the neighbouring 8 cells of a MN. Therefore, the MN has been extended to 25 cells where the agent can move to its neighbouring 24 cells in a single time step as shown in Figure 2(c).



(a) Von Neumann Neighbourhood (b) Moore Neighbourhood (c) Extended Moore Neighbourhood

Figure 2. Agent Neighborhood

According to the layout of the lecture theatre and the initial location of agents in the seating area (coloured yellow in Figure 1), algorithmic steps of each agent's evacuation process are defined in three stages. Prior to defining these stages, it is noted that at every time step an agent calculates the distances between itself and different ECs in order to choose the nearest one. The chosen EC is called the Goal Exit Cell (GEC).

Stage 1: If an agent is located in the seating area, then

If it is in the left area (or right area) (see Figure 1), then move to the aisle to the right (or left).

Else if it is in the middle area (see in Figure 1): (1) the agent determines the closest AC; (2) if the closest AC and GEC are both on the left side (or right side) of the agent, then it will choose to move to the left (or right); (3) else the agent determines the AC closest to its GEC and there is a probability of moving to the closest AC or moving to the AC closest to its GEC. The chosen AC is called the GAC.

Stage 2: If the agent has left the seating area and is located in an aisle, then it moves along the aisle towards its GEC. The agent does not always move in a straight line due to the occupancy of surrounding cells. For example, if the cell in front of the agent is empty, then the agent will move into this cell. Otherwise, the agent will attempt to move to an AC which is empty.

Stage 3: If the agent has left an aisle, then it moves towards its GEC. At one space step, the Goal Cell (GC) of the agent will be selected from its MN. Here, the GC is used to refer to the cell that an agent chooses to move to at each time step. If the GC is closer to the GEC than the cell that the agent currently occupies, then it will move to the GC; else the agent will stay in the same location.

Individual Behaviour

Competitive behaviour, cooperative behaviour and conflict - In an evacuation situation, as time elapses people's stress level is likely to increase. Driven by high levels of mental stress, people will behave in a competitive manner (Pan 2006, Fang et al. 2016). In this model, a numerical stress level is used with the initial stress level of all agents being set (the same or different) before a simulation is carried out. At each time step, the stress level of an agent will increase by a defined quantity. A parameter *stress threshold* is used which is a boundary condition that measures the effects of stress (Pan 2006). When agents have a stress level that exceeds their stress threshold, they will no longer behave cooperatively, rather the agents will exhibit competitive behaviour.

Competitive behaviour is frequently observed in emergency evacuation situations when people compete for opportunities to evacuate more quickly. In this model, a competitive agent (competitor) executes the following behaviour rules.

(1) Move to its GC even if the cell is occupied by one agent or two agents.
(2) Move two space steps in one time step providing the movement rules allow; for instance, if the competitor's GC at some time step is already occupied by three agents, then it cannot move to its GC. The extended MN is used here as the movement range of the competitor is 24 cells.
(3) All agents with the same GC in a normal MN are called a group. In such a group, competitors are

allowed to move before co-operators. However, in a group with more than one competitor, conflicts between these agents can arise, thus preventing movement. The rules for representing a conflict will be discussed after cooperative behaviour.

Cooperative behaviour is likely to happen in emergency situations as recent work has proposed that people perform complex behaviours in emergency evacuation (Challenger et al. 2009, Aguirre et al. 2011, Fang et al. 2016) and they can evacuate in an ordered and cooperative manner not just competitive behaviour (Fang et al. 2016). In this model, a cooperative agent (co-operator) has the following behaviour rules.

(1) Move to its GC only if the cell is empty. If the GC is occupied by one or more agents, the co-operator will not move in this time step.
(2) Move one space step in one time step when the GC of the agent is empty. Otherwise, do not move in this time step. The MN is used here since the movement range of a co-operator is 8 cells.
(3) Within a group (as defined previously), co-operators will allow competitors to move first. If all agents in a group are cooperative, one of them is randomly chosen to move.
(4) When there are agents falling down in a co-operator's MN, the co-operator will carry out altruistic behaviour, i.e. the agent will temporarily ignore its GC and head to the falling agent in its MN.

Conflict between competitive agents can arise in evacuation situations. If there are M agents in a group and N of them are competitors then $\mathrm{M}-\mathrm{N}$ of them will be co-operators. At a particular time step, the co-operators in a group do not move whereas each of the competitors has the same probability of moving, Competitor Move Probability (CMP),

$$CMP = \begin{cases} 1, & CA = 0 \\ 1/(\mathrm{N} \times CA), & CA > 0 \end{cases} \tag{1}$$

where CA is a measure of a competitors' Conflict Attitude ($0 \leq CA \leq 2$) (Bouzat and Kuperman, 2014). The stronger the CA of competitors in a group, the greater the value of CA and the lower the CMP. Equation (1) is adapted from Bouzat and Kuperman's equation (Bouzat and Kuperman, 2014), a form of which can be stated as,

$$CMP = \begin{cases} 1, & CA = 0 \\ 1/(N^2 \times CA), & CA > 0 \end{cases} \tag{2}$$

Values of CMP obtained using equation (2) can be too low to reflect the probability of competitors moving in the scenarios considered in this paper. Thus, equation (1) is more appropriate for this model. When competitors do not conflict with each other, the value of CA is 0 and one of the competitors is randomly selected to move. The upper limit of CA is 2 because agents focus more on successful evacuation rather than engaging in conflict with no end. It is assumed that values of P of all competitors are the same. The Conflict Degree of a Group (CDG) is the product of N and CA and refers to the competitive degree of the whole group. Equation (1) demonstrates that at some time step, CMP decreases as N or CA increase. In real evacuation situations, many people compete for one place and the action of these people will lead to it being difficult for all of them to move at the same time. This is called the "Faster is Slower" effect which means that in some situations, if people push harder when trying to exit a room through a door, the evacuation time can increase (Helbing et al. 2000).

Climbing behaviour - In reality, a person who sits far away from the aisle may need a long time to walk through the seating area (coloured yellow in Figure 1) which is occupied by other people. If the person is located in the first two rows or the last two rows, he/she may climb over desks or seats in an attempt to reduce their evacuation time. For example, in Figure 1, the agent (denoted by the blue circle in Figure 1) can move directly towards the exit after climbing over the desk immediately in front of it. In this model, an agent has a likelihood to climb over desks and seats when the location of the agent meets two conditions. One condition is that the agent is located in the first two rows or the last two rows of seating in the lecture theatre since when the agent is situated in other rows it is not time-saving to climb over desks and seats. The other condition is that the agent is situated more than three cells from its GAC since if the agent is nearer to the GAC then it would be time-saving to walk rather than climb over obstacles.

Falling down behaviour - Heliövaara et al. point out that it would be a topic for future modelling to develop their model to enable agents to fall down (Heliövaara et al., 2013). In this model, it is assumed that when an agent competes with other agents or tries to climb over obstacles, there is a probability of falling down. If an agent falls down and does not receive help from other agents, it will remain in the same location for five time steps and then resume evacuating. However, during the period of remaining still, the agent that has fallen down can recover and then move immediately if an agent demonstrating altruistic behaviour arrives at its location in order to help.

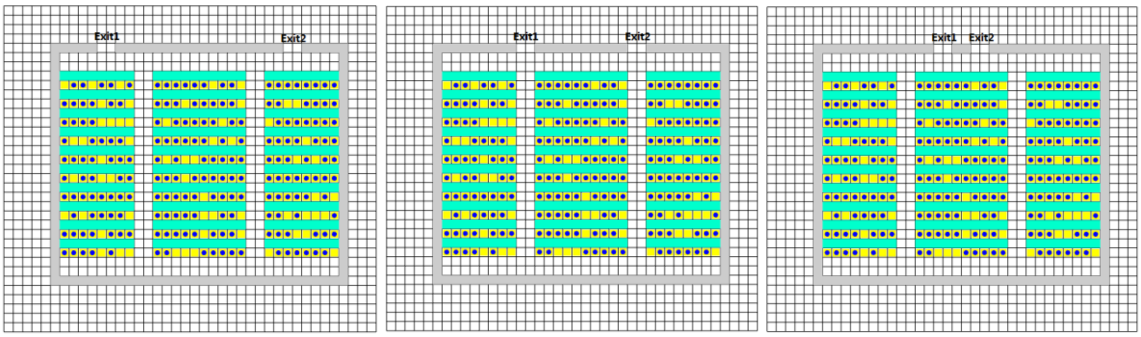
INITIAL SIMULATION RESULTS

Agent-based simulations have been carried to examine the effect on evacuation of (1) exit location and (2) competitive behaviour.

Effect of Exit Location on Evacuation

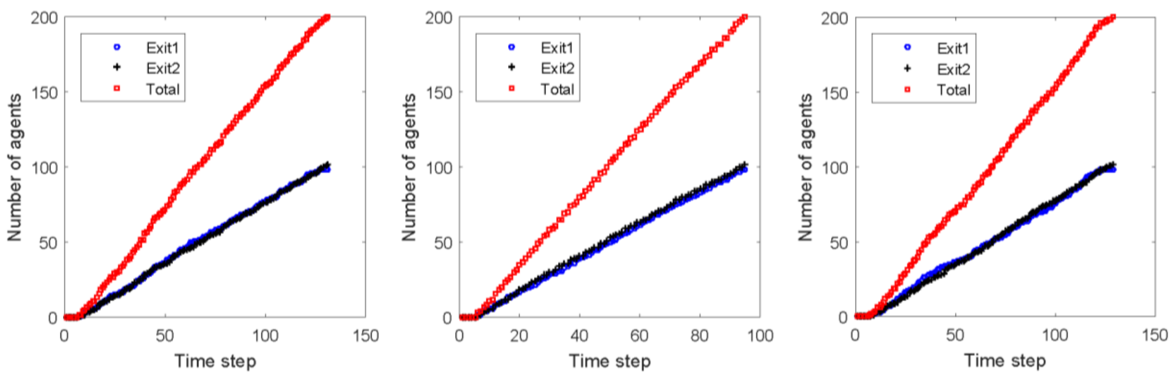
Three scenarios have been simulated each with different exit locations in the lecture theatre, S1-S3, as illustrated in Figure 3. In these simulations, agents behave according to basic movement as outlined in the previous section. Based on the actual layout of a lecture theatre with dimensions approximately 15m × 12m, the size of the lecture theatre modelled is 30 × 24 cells and the numbers of rows and columns of seating are 10 and 26 respectively. In each simulation, 200 agents are distributed in the lecture theatre with 57, 79 and 64 agents initially located in the left, middle and right seating areas respectively. While this initial distribution of agents is random, it has been kept the same in each simulation in order to ensure the results can be compared to each other. Furthermore, the simulation for each scenario has been repeated 10 times.

Figure 4 shows the relationship between the number of evacuated agents (total evacuated agents, evacuated agents via Exit 1 and evacuated agents via Exit 2) against time for each of the three scenarios simulated. From Figure 4, it can be seen all of the relationship curves are approximately linear, which can be attributed to the agents executing basic movements such that they evacuate in an ordered way and the moving velocity of the whole crowd is stable. Also, the relationship curves of agents evacuating through Exit 1 and Exit 2 are almost coincident, which can be explained by the near-uniform initial distribution of agents' locations and agents always choosing the nearest exit to egress. The mean evacuation time for each scenario is presented in Table 1 in which it can be seen that the evacuation time for S1 and S3 are approximately equal. It is noted that in S1 and S3, Exit 1 (the left exit) is distributed symmetrically about the left aisle. Similarly, Exit 2 (the right exit) is distributed symmetrically about the right aisle. It is suggested that the relative location between the exits and aisles in S1 and S3 is the reason why their mean evacuation times are approximately equal. In Table 1, it is also seen that the mean evacuation time of scenario S2 is approximately 30 time steps lower than that of S1 and S3. As intuitively expected, with the exit locations in alignment with the aisles in S2, once agents are in the aisles they are able to move directly to the exits without turning left or right thus improving evacuation efficiency.



(a) S1 (b) S2 (c) S3

Figure 3. Lecture Theatres with Different Exit Locations



(a) S1 (b) S2 (c) S3

Figure 4. Number of Evacuated Agents versus Time

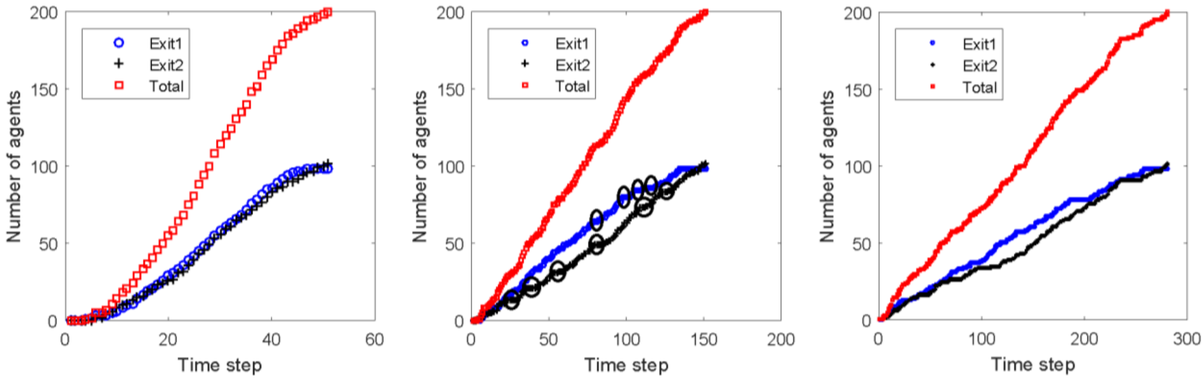
Table 1. Mean Evacuation Time

	S1	S2	S3
Evacuation time	129.1	97.4	129.4

Effect of Competitive Behaviour on Evacuation

In examining the effect on evacuation of competitive behaviour, the lecture theatre layout of scenario S2 has been selected (illustrated in Figure 3(b)) given this yielded a lower mean evacuation time than S1 and S3 in the simulations reported earlier. Furthermore, in examining competitive behaviour, three cases are considered. Case 1 (C1) involves no conflict between competitive agents (with CA = 0 in equation (1)). In Case 2 (C2) and Case 3 (C3), varying degrees of conflict exists between competitive agents. Specifically, in C2, CA = 1 (in equation (1)) whereas in C3, CA = 2 (in equation (1)). To reflect variation in individuals, the initial stress level of each agent ranges from 0 to 30 with the stress threshold set as 30. When an agent's stress level exceeds 30, the agent will stop behaving in a cooperative manner and begin behaving in a competitive manner. Simulations for these three cases have been repeated 10 times with the same initial distribution of agents as seen in those conducted when examining the effect of exit locations on evacuation.

Figure 5 presents the relationship between the number of evacuated agents (total evacuated agents, evacuated agents via Exit 1 and 2 respectively) against time for the three conditions simulated.



(a) C1 (b) C2 (c) C3

Figure 5. Number of Evacuated Agents versus Time

For C1, in which conflict does not exist between competitive agents, Figure 5(a) indicates that the total number of evacuated agents (shown in red) increases at a rate of approximately 0.6 agents per time step from 0 to 10 time steps, 2.3 agents per time step from 10 to 20 time steps, 2.9 agents per time step from 20 to 40 time steps, and 1.2 agents per time step from 40 to 50 time steps. The increase in evacuation rate beyond 20 time steps could be attributable to almost all 200 of the agents changing their behaviour from cooperative to competitive, due to their stress threshold being exceeded, by this time step in the simulation. Once an agent exhibits competitive behaviour, it is able to move two spaces steps in a single time step to reach its GC even if occupied by one or two other agents. Also in Figure 5(a), the evacuation rate of agents via Exit 1 (shown in blue) and Exit 2 (shown in black) is seen to be approximately the same.

For C2, in which a degree of conflict exists between competitive agents, it can be observed in Figure 5(b) that the total evacuation rate fluctuates throughout the simulation period. Furthermore, it can be seen that at certain points no agents evacuate the lecture theatre via Exits 1 and 2; four 'plateaus' (highlighted by black circles) for Exit 1 (shown in blue) and six plateaus (highlighted by black circles) for Exit 2 (shown in black). It is suggested that these periods on non-evacuation occur due to conflict between competitive agents. Also seen in Figure 5(b), evacuation via Exit 1 (shown in blue) is greater than that via Exit 2 (shown in black). This feature corresponds with the fact that conflict between competitive agents via Exit 2 is greater than that via Exit 1, shown by more 'plateaus' of non-evacuation in Exit1 than Exit 2.

For C3, in which a greater degree of conflict exists between competitive agents (than in C2), Figure 5(c) shows that the total evacuation rate fluctuates more frequently throughout the simulation period than that of C2 in Figure 5(b). Also, for C3, in considering evacuation via Exit 1 and Exit 2, it can be observed in Figure 5(c) that no agents evacuate the lecture theatre at more points during the simulation than in C2 (shown in Figure 5(b)); approximately ten and thirteen 'plateaus' (not highlighted) for Exit 1 (shown in blue) and Exit 2 (shown in black) respectively. This may be the reason why the total evacuation curve in Figure 5(c) shows more fluctuations than that of Figure 5(b). Furthermore, in Figure 5(c), evacuation via Exit 1 is greater than that via Exit 2 from approximately 100 to 200 time steps. This corresponds to the fact that evacuation via Exit 2 has more instances (approximately 3) when no agents evacuate the lecture theatre than via Exit 1.

Table 2 indicates the mean evacuation times for C1, C2 and C3, using the lecture theatre layout of scenario S2 with exit locations in alignment with the aisles.

Table 2. Mean Evacuation Time

	C1	C2	C3
Evacuation time	41.1	138.5	274.8

From Table 2, it can be seen that the evacuation time for C1 in which conflict does not exist between competitive agents is significantly less (a factor of 3.4) than that for C2 where competitive agents have a degree of conflict. In addition, the evacuation time for C2 is less (a factor of 2.0) than that for C3 where competitive agents conflict with each other to a greater degree.

CONCLUSION AND FUTURE WORK

The ongoing research reported in this paper is aimed at designing an agent-based modelling and simulation system to provide decision support for the layout design of lecture theatres and human behavioural management in emergency evacuation. Research to date has produced an initial system that enables (a) the design of the spatial layout of lecture theatres, and (b) evacuations to be simulated via an agent-based model incorporating behaviours in terms of basic movement and at an individual level. A preliminary investigation has been undertaken to examine the effect of exit location and competitive behaviour on evacuation time. Simulation results show that evacuation efficiency is improved when exits are in alignment with aisles. Furthermore, results show that competitive behaviour does not always increase the evacuation time depending on if the competitive agents conflict with each other. Although the simulation experiments may be intuitive, they provide a foundation for more complex scenarios to be considered. Future work will focus on further development of spatial layout design and agent behaviours. First, the spatial environment of the model will move from a single lecture theatre to a floor of a building with multiple rooms such as lecture theatres and small classrooms to a whole building with multiple floors. In addition, the model will take group behaviour and crowd behaviour into account to represent agent behaviour closer to reality. Also, future work will concentrate on customization that allows user definition of different spatial environments and agent behaviours. With all these efforts, the system can be used by emergency managers, designers and administrators who are charged with disaster mitigation in educational establishments to (1) evaluate the effects of different layouts on crowd evacuation dynamics and (2) better manage human evacuation behaviour.

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An interactive simulation for testing communication strategies in bushfires

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ABSTRACT

Australia is frequently hit by bushfires. In 2009, the ”Black Saturday” fires killed 173 people and burnt hectares of bush. As a result, a research commission was created to investigate, and concluded that several aspects could be improved, in particular better understanding of the population actual behaviour, and better communication with them. We argue that agent-based modelling and simulation is a great tool to test possible communication strategies, in order to deduce valuable insight for emergency managers before new fires happen. In this paper, we extend an existing agent-based model of the population behaviour in bushfires. Concretely, we added a communication model based in social sciences, and user interactivity with the model. We present the results of first experiments with different communication strategies, providing valuable insight for better communication with the population during such events. This model is still preliminary and will eventually be turned into a serious game. . . .

Keywords

Agent-based modelling and simulation, communication, crisis management, GAMA platform, serious game

INTRODUCTION

Nowadays, the number of crisis events is continuously increasing, be they natural crises (fires, floods, earthquakes, tsunamis...) or man-made crises (industrial accidents, terrorism, refugees flow...). Societies can manage crisis and emergency situations in several ways: adopt urban and territory planning policies to reduce the risks (*e.g.* forbid construction in exposed areas); raise awareness and prepare the population in advance; or create efficient emergency management policies to deal with crises when they happen.

Modelling and simulation offer tools to test the effects and complex interactions of these different strategies without waiting for an actual crisis to happen, without putting human lives at risk, with limited cost, and with a great degree of control on all conditions and the possibility of reproducing exactly the same situation as many times as needed. When modelling human behaviour, mathematical, equation-based models are too limited (**parunak1998**). On the contrary, **agent-based models**, where autonomous entities (agents) interacting with each other represent the humans involved, offer many benefits (**bonabeau2002**). They allow capturing emergent phenomena that characterise such complex systems; they provide an intuitive and realistic description of their behaviour; they are flexible, offering different levels of abstraction by varying the complexity of agents.

In this paper, we are particularly interested in the bushfires that strike the state of Victoria in Australia every summer, burning many hectares of forest, causing many deaths and injuries, and destroying property. (**Dutta2016**) have recently shown a 40% increase in the number of bushfires per week in Australia over 5 years (from 3284 per week in 2007 to 4595 events per week in 2013). The current state policy is ”Prepare, stay and defend, or leave early”, so the population is given a choice between: evacuating early, before fire reaches their area of residence, because "many people have died trying to leave at the last minute" (**cfa-guide**); or stay and defend their house, only if very well physically and mentally prepared. In both cases, the decision must be made and a plan prepared well in advance. But in the summer 2009, serious bushfires devastated a part of Victoria, culminating on the Black Saturday 7th February when 173 people died despite all efforts at raising awareness. The cost of these bushfires was estimated to 4.4 billion dollars, with 98932 hectares of Victorian parks damaged, an estimation of one million animals dying, cost to agriculture due to loss of cattle and pastures, etc.

Several reports (**royalcomm2009**; **murrindindi2011**) have tried to explain the reasons for this heavy death toll, and have identified different inconsistencies: in **behaviour** (the population does not react as expected by decision-makers), in **information** (received information is not always considered as relevant by the population), and in **communication means** (inefficient, specifically information *broadcast*). As said by (**why2014**): ”agencies need to change from an expert authoritative approach to one that seeks to understand community needs and expectations”.

Adam *et al.* (**AdGa2016ssc**) have designed a model of the behaviour of the Australian population in bushfires from interviews gathered after the 2009 "Black Saturday" fires by the Victorian Bushfires Research Commission (**statements2009**) to explain the inconsistencies in behaviour in terms of a gap between objective and subjective evaluations of risk and capabilities to deal with it. In this paper, we are interested in the other inconsistencies noted in the report, namely the **communication problems** *i.e.* the fact that the content of information communicated to the population, and the means of communication used, were not optimal.

Our goal is to turn Adam *et al.* 's model into an interactive simulation where the user can **test different communication strategies** (changing the source, media, content or recipient of messages) and obtain indicators of their relative success. For such an interactive simulation to lay valid results, it is important that the underlying human behaviour model be as realistic as possible (**Ruijven2011**). The underlying agent-based model was proven valid (**AdGa2016ssc**) and successfully compared with another more complex model (**AdTaDu2017hicss**). Here we enrich it with a communication model in order to allow the agents to receive messages and to reason on their content and sender. To ensure the validity of these additions, our communication model is grounded in theories from social sciences that have studied communication issues for a long time.

The paper is structured as follows: we first introduce some relevant literature regarding serious games, communication theories, and cognitive biases. We then proceed to presenting our methodology, data, simulation platform, and the model we are extending. The next section then describes our model of communication and its implementation in this existing simulator. The following section exposes our experiments and results with this interactive simulator. Finally we conclude the paper by discussing the limitation of our approach and its future prospects.

STATE OF THE ART

Participatory simulation for raising awareness

Computer simulation is a great tool for crisis management that offers many benefits. Compared to full-scale simulation exercises, it is much less costly, less dangerous, and easier to organise. Yet it still allows to discover knowledge by exploring several ”what-if” scenarios before an actual crisis happens, with complete control on all parameters. Participatory simulation is a type of simulation where human users interact with the simulated world by controlling some of the agents in the system. Participatory simulation is therefore a type of serious games, *i.e.* games that are used not for entertainment but for learning, training, or understanding mechanisms (**MIC06**).

Serious games have several benefits over more classical approaches to teaching or raising awareness. They follow a constructivist logic in which the players build their own knowledge by confronting a problem in a simulated world. A meta-analysis gathering 193 articles about serious games (**SAU07**) has shown many benefits such as: favouring the development of social and human relationships and communication skills; increasing learning motivation, self-esteem and self-confidence, engagement and persistence; developing problem-solving skills; helping learners to structure, build and represent knowledge; and helping learners to integrate information by developing the capability to build links and transfer knowledge from other contexts.

Simulation-based serious games are particularly interesting for raising awareness of various types of risks (**CRO16**). By being placed in a risky situation and allowed to try several ways of managing it, the players can better comprehend the risks and their possibility of occurrence, but also the consequences of their actions of these risks. For major risks such as bushfires, exploring different strategies and their impact in a serious game provides players with some experience, simulated but close to the real world mechanics. Such experience would be hard to acquire from real crisis in such a short time, due to the long duration between events (several months to years), and the stakes involved that prevent from trying blindly. An important aspect of serious games and participatory simulations is to rely on a pedagogical scenario integrated in the game design to answer a specific pedagogical objective (**CHA15**), and on well-specified rules (objectives, conditions of victory, possible interactions...) to guide the player.

Communication theories for crisis management

In his well-known Communication Theory, Shannon (**shannon1948**) devised a model of communication with the following components: information source, transmitter (encoder), transmission channel, receiver (decoder), destination, and message. Among these components of a message, the **channel** has already been largely studied in crisis management. For instance some works show a significant "channel effect" of social media (**SUG2011**; **USG2013**), where the same message has a different effect depending on which channel it is delivered on (social media vs more traditional channels). Trust in the **source** of the message is also important and depends on their trustworthiness, expertise and attractiveness (**PeCa1986elm**).

Regarding the **message** itself, Speech Acts Theory (**searle1969**; **vanderveken1990**) exhaustively lists the 5 types of messages that can be communicated: assertive (state a fact, provide an information), promissive (commit to perform an action), directive (ask or order the hearer to perform an action), expressive (express an emotion), and declarative (formal institutional action such as declaring someone married, or guilty). Most relevant in crisis management are assertive and directive speech acts, in order to provide the population with information and recommendations.

Regarding the **recipient**, (**devito2000**) has divided the listening process into 5 sequential phases that occur after actually hearing the message: receiving (or attending, *i.e.* actually focusing on the message), understanding (getting the meaning of the message), remembering, evaluating (forming an opinion about the validity of the message), and responding (*i.e.* provide feedback regarding acceptance of the message). This final stage can be in the form of direct feedback, or just by changing behaviour as a result of the message.

Communication can fail at any stage of this process. The message might not be heard if the recipient is not monitoring the channel (TV or radio is off). Even if the message is heard, it might not be attended to or remembered if the hearer is overwhelmed by receiving too much information at the same time (information overload); the hearer might miss relevant data that is drowned in too many irrelevant messages, which might lead them to stop listening to a given emitter because they cannot deal (**APF1999**). If attended to, the message might be evaluated as irrelevant or inaccurate and discarded. Finally, even if the message is considered accurate, it might not lead to the expected behaviour change.

Behaviour change

Messages sent by emergency managers during disaster often aim at changing the population's behaviour towards what they consider to be the best response (evacuate to a safe area after an earthquake, stay confined inside during a chemical incident, etc). Behaviour change has been extensively studied (see (**prager2012**) for a review), but a lot of works focus on medium or long-term changes (*e.g.* non-healthy habits like smoking) while bushfires are short-term emergency situations.

The Elaboration Likelihood Model (**PeCa1986elm**) is a theory describing how attitudes can be changed by persuasive stimuli. It distinguishes two types of processing: central (cognitive, high effort) and peripheral (heuristic, low effort).

- The **central route of processing**, used when the individual is motivated and able to process the message carefully, is a more cognitive, high-effort elaboration of the message received, based on its actual logical value. As a result, it leads to more resistant attitude change, and is more predictive of behaviour change.
- The **peripheral route of processing**, used to reduce mental efforts when the individual is not motivated or unable to process the message, is a less thorough elaboration of the message that relies more on cues and heuristics. For instance it focuses on the credibility, attractiveness or familiarity of the source, at the expense of the actual logical value of the content. It is therefore more influenced by mood, or by emotions towards the emitter.

Individuals try to reduce their mental efforts and will thus tend to use the peripheral route, unless they are sufficiently motivated and able to elaborate on the message.

- **Motivation** is affected by the relevance, interest and consistency of the message with the recipient's current beliefs (contradictory messages are more easily rejected); it is also affected by the recipient's personality (do they like thinking, whatever the subject).
- **Ability** is affected by the recipient's knowledge (is it sufficient to critically evaluate the content of the message) and familiarity with the subject, and the availability of their cognitive resources (how busy or distracted they are, time pressure).

As we can see, peripheral processing is more likely to happen during disasters due to the stress and time pressure. However, it leads to less lasting attitude changes and is less likely to trigger behaviour change. Crisis communication should therefore be adapted so as to favour central processing, by sending only clear, understandable and relevant information.

Cognitive biases

Message acceptance and behaviour change is also impacted by various cognitive biases, phenomena described in psychology and social sciences that twist reasoning towards ”irrational” shortcuts in order to make faster decisions. They are particularly relevant during crises (**yudkowsky2008**; **KKRP2014**) when decisions are made under high stress and time pressure.

Previous studies (**AdGa2016ssc**) have found occurrences of these cognitive biases in the population interviews performed after the bushfires (**statements2009**). For instance :

- the *confirmation bias* is a tendency to give more credit to information confirming existing beliefs and to discard inconsistent information (*e.g.* interpret the presence of firemen as a cue that everything is safe in order to confirm motivation to stay);
- over-estimation of danger to others and under-estimation of danger to self (residents often report they knew there were going to be fires but felt they were not going to be impacted; however many residents worried for their friends, neighbours and relatives);
- the *anchoring effect* is an excessive focus on the first information received that prevents from changing one’s initial decision even when receiving further (possibly contradictory) information (the authorities report an over-commitment of residents to their defense plan even when the fires were known to be much too strong to be fought);
- the *bandwagon effect*: doing and believing the same as others around (*e.g.* residents who believe it is safe because their neighbours stay);
- the *sunk cost fallacy* consists in refusing to abandon a goal even when new information would require it, because of having already invested in it. It is therefore self-reinforcing as more actions are performed to reach the goal (*e.g.* residents who have invested a lot in building and preparing their house to resist the fires are less likely to abandon it, even when informed they should evacuate).

Behaviour profiles in bushfires

Alan Rhodes (**why2014**) has extracted 6 behaviour profiles of the population in bushfires.

- **Can do defenders:** skilled and experienced defenders, relying nearly only on their own abilities to manage the situation;
- **Considered defenders:** good defenders with several possible plans to deal with fires; they are more likely to listen to warnings from the authorities than Can do defenders;
- **Livelihood defenders:** will protect their property whatever the danger, because it is their source of income;
- **Threat monitors:** focused on defense but will immediately escape if they feel a real danger;
- **Threat avoiders:** focused on escape, will decide to run away as soon as they are aware of fires;
- **Unaware:** do not feel concerned by fire risk, and do not known how to react in case of a fire.

However, he provides no information about the distribution of these profiles in the population, and states that they are not linked with demographic features.

OUR MODEL

Based on these elements, we designed an interactive simulation of the population behaviour in response to various communication strategies during bushfires. Our simulation is implemented in GAMA, and based on an existing simulator, extended here with a communication model grounded in the theories presented above.

GAMA platform

GAMA (**GAMA2013**; **Drogoul2013prima**; **Drogoul2013paams**) is an open-source platform for agent-based modelling and simulation, offering an integrated programming language and development framework to develop elaborated models with up to several millions of agents. The GAma Modelling Language (GAML) is a high level agent-based language based on Java, specifically designed to be easy to use even for non-computer scientists, allowing domain experts to create and maintain their own models. GAMA also provides native management of GIS (Geographical Information Systems) data allowing to integrate geographical data files into simulations. Finally, GAMA offers interactive functions (user commands) enabling the use of the participatory dynamics required in our interactive simulation.

Existing simulator

Adam and Gaudou (**AdGa2016ssc**) have implemented in GAMA an agent-based simulator of the behaviour of the Australian population in bushfires, based on the population interviews gathered after the 2009 fires (**statements2009**). In their simulator, the world is a grid of 50*50 cells inhabited by four species of agents: fires, houses, shelters and residents.

Fires are reactive agents; they are initially placed randomly on a free cell and then grow up randomly at each cycle, increasing their intensity (which directly increases the damage they deal) and size. People cannot go through fires when escaping but can cross their area of effect (representing the smoke and heat zones around the fire). When all fires are extinguished, the simulation stops automatically.

Houses are inhabited by exactly one resident (no families). They offer some amount of protection but residents can still be hurt if fires are close enough. Houses can be reinforced by their owner up to a given point while fires are still far away. When fires are close enough, they deal damage to the house until possibly destroying it.

Shelters are safe areas where people cannot be harmed by fires. Residents know the location of some shelters, and when choosing to escape they aim at the closest one they know (which might not be the absolute closest one if they ignore its location).

Finally **residents** are the most complex agents in this simulator. They have various attributes to represent their health, their motivations (to defend or to escape), their risk perception (awareness of fire, assessment of danger), and their abilities. Their possible actions are to prepare their house and themselves, to escape towards a shelter, to defend against the fire, or to take cover in their house. The choice of action is determined by a finite state machine architecture (see Figure 1): in each state, the corresponding action is performed, and the transitions to another state are constrained by the values of attributes and the position of fires.

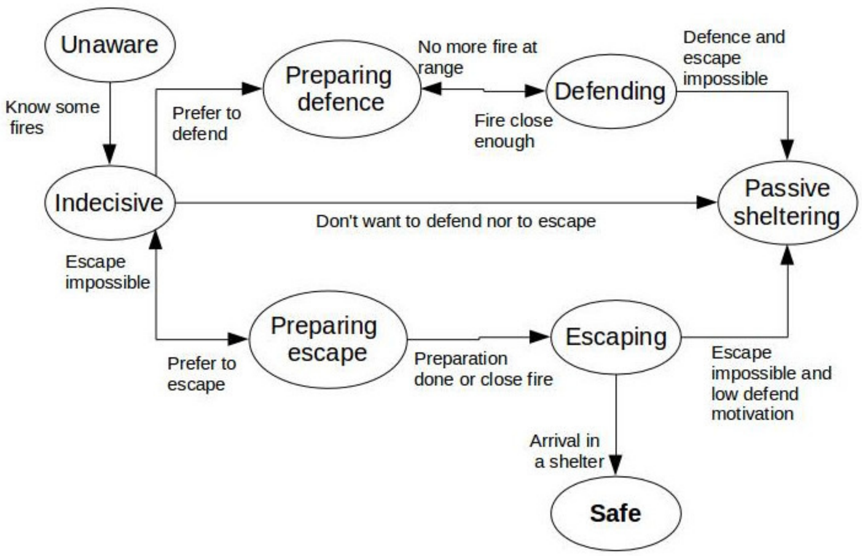

Figure 1. Finite state machine architecture of residents agents

The following paragraphs describe the extensions we performed on this model.

Communication strategies

Based on the communication theories presented above, we modelled several types of communication strategies, that concern the different components of a message, namely the choice of its source (authorities, fire soldiers, general media...), its content (information, recommendations), and its target (all the population, a precise geographic area, or a specific category of residents).

- *Content-based* strategies are focused on what is concretely told to residents. We modeled two of the 5 types of speech acts: information about fires (*e.g.* position) and recommendations (advice about the appropriate behaviour, *e.g.* evacuate). Indeed, these are the ones most frequently related by the residents in the interviews, either because they received them, or because they wish they had received them.
- *Target-based* strategies concern the accuracy of messages. We modeled three possibilities: global broadcast (target all residents), geographical-based (target people in a specific area), and plan-based (target residents based on their declared fire plan: defend or escape).
- *Source-based* strategies concern the emitter of the message. We have implemented different possible sources (firemen, authorities...) as well as indirect communication strategies where global authorities send messages to local managers (*e.g.* mayors) who filter them and spread relevant data to their neighbourhood. *Composed* strategies consist in sending a sequence of messages in a precise order. This type of strategies aims at determining if it is efficient to send a combination of several messages, and which order of messages is most efficient (for instance inform about fires before or after giving recommendations).
- Finally we also implemented various *shelter-based* strategies in order to compare the efficiency of building many shelters vs communicating more about the existing ones. These are therefore not strictly communicative strategies as the player can also choose to create new shelters. Shelters are designated safe areas (cricket oval, community house, etc) where residents are invited to gather in case of a fire.

We implemented these communication strategies in the existing GAMA simulator in the form of user actions: the user can right click in the simulation window at any time during the simulation; they are then invited to select a communication strategy and specify its features (source, channel, etc) before executing it. Each communication action has a different cost (for instance it is more costly to accurately target communication than to broadcast, and more costly to build shelters than to advertise them). In the next paragraph, we describe how we also updated the residents model to allow these agents to receive messages, interpret them, reason on them and make relevant decisions so as to change (or not) their subsequent behaviour.

Psychological aspects of decision making

In order to obtain a realistic model of residents and of their handling of messages, we implemented several psychological phenomena based on the theories exposed above.

Profiles of behaviour

We implemented the different profiles of behaviour in terms of ranges of values of their attributes, and modified transitions in the finite-state machine. For instance livelihood defenders cannot escape but are more likely to shelter if needed; they also have a high ability to fight fire and a high trust in local sources. The type of population can be selected as a simulation parameter.

Trust in message source

Trust is one of the most intuitive aspects involved in communication. If the source of the message is not trusted, the receiver is not likely to take its content into account. In our model, residents have a "trust probability" attribute: it is a table matching each source with a probability to trust the messages it sends. The values in the trust table depend on the resident's profile. For example, *Can do defenders* have a higher trust in local sources of information than *Threat monitors*, but a lower trust in firemen.

Message acceptance

To represent the information overload phenomenon, we added an acceptance probability for each source in the pedestrian attributes. The initial values are based on the resident's trust in each source. When a resident receives a message, they might accept or reject it based on the resident's acceptance probability for its source. The resident then updates their acceptance according to the message accuracy and its perceived relevance. Thus, if the message is perceived as inaccurate (too global or imprecise) or useless, the resident's acceptance probability for messages from this source will decrease; on the contrary relevant messages will increase this acceptance probability.

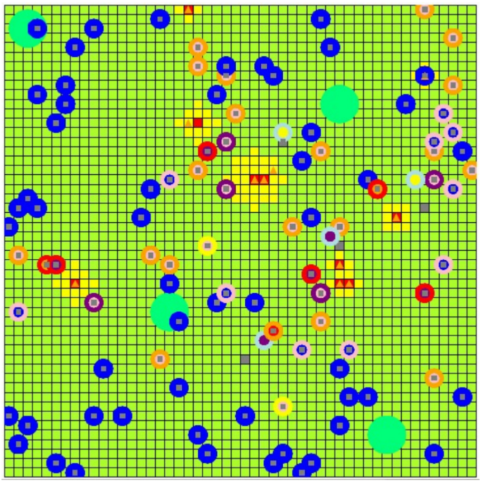

Figure 2. Screenshot of the graphical experiment in GAMA

Cognitive biases

A number of biases are taken into account in our model. For instance the confirmation bias and anchoring effect are implemented by the fact that the resident's motivation influences their risk assessment and vice versa: a resident motivated to defend will under-estimate risk (and discard cues of a higher risk), and low estimation of risk will increase their defense motivation (defense becomes an anchor). The sunk-cost fallacy is implemented thanks to the feedback from actions: the defense motivation gradually increases with successful defense actions, making it harder to give up defense.

EXPERIMENTS AND RESULTS

This section presents our first experiments with this model. Below we define the scenarios that we want to test (*e.g.* compare broadcast with personalised communication), as well as the indicators used to measure success of the compared strategies, before describing our results.

GAMA experiments

The GAMA platform allows two types of experiments:

- Graphical experiments: we run one simulation and observe the behaviour of the agents "live" to have a quick overview of their reaction to various strategies. (See a screenshot on Figure 2.)
- Batch experiments: automatically run many iterations of each simulation (with the same parameters). In that case there is no graphical display but GAMA outputs graphs of the average values (over all iterations) of selected indicators, which allows to smooth out the randomness of the simulation.

Scenarios.

In this paper we describe the results of batch experiments for 4 scenarios that compare communication strategies with each other, depending on the target population. Here we focused on 2 of the 6 profiles of behaviour, namely the can-do defenders (planning to defend their property) and the threat avoiders (planning to escape fires).

- Scenario 0 is our baseline: we compared the values of all indicators on the two populations without any communication.
- Scenario 1: compare possible **contents** of strategies (give information about fires vs recommendations) on these 2 populations
- Scenario 2: compare the **accuracy** of communication campaigns (broadcast vs geographically-targeted vs plan-targeted)
- Scenario 3: compare **shelter-based** strategies on the 2 populations

Indicators. To be able to compare the different strategies, we defined and implemented the following indicators measuring their relative success or failure: number of deaths; number of injuries; total damage to houses; total cost of communication actions.

Settings. For each scenario (comparing several simulations), we ran 60 iterations of 200 cycles of each simulation (which represents over 3 hours of simulated time with one minute long cycles). Between the compared simulations, we only varied the communication strategy tested, with the other parameters being exactly the same (number and strength of fires, population, availability of communication channels...).

Output. The output of our batch experiments consists in graphs showing the comparative average values of these indicators for different strategies. The graphs obtained for the scenarios defined above are discussed below.

Scenario 0: baseline, no communication

We first compared the impact of fires on the two populations when there is no communication actions performed. With the threat avoiders population focused only on escape, and since we did not implement firemen in our simulation, we expected the fires to grow out of control and lead to a high number of victims and great amount of damage. There was indeed a huge gap (in terms of damages, injuries and deaths) compared to the can-do defenders population. The next scenarios compare the impact of various strategies on these two different populations.

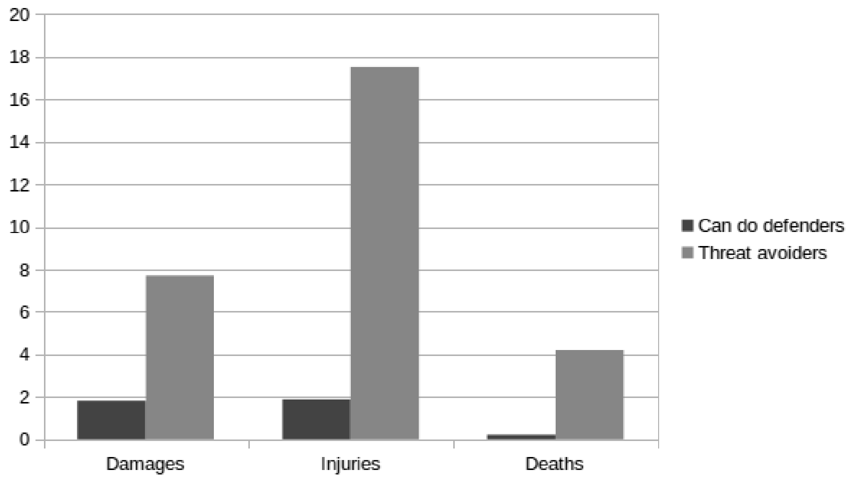

Figure 3. Comparing Can-do defender and Threat avoider populations - no communication

Scenario 1: comparing information vs recommendation messages

Can-do defenders. As expected with such skilled defenders, values of building damage, injuries and deaths are quite low. As shown on Figure 4, there is no big differences between broadcasting fire information and recommendations in terms of damage or cost. There are slightly more injured and dead with recommendations only. Our data allows to explain this observation: in the absence of information messages, many residents remain unaware of the fires (too far to be perceived directly) so they do not feel concerned and ignore recommendations. As a result they do not prepare and end up being more vulnerable when the fire arrives. Since less people defend, the fire grows faster and later blocks or injure escapers. On the contrary with information only, residents are aware of all fires even far away, which increases their subjective risk perception and in turn influences their behaviour: more people escape early and stay safe. The difference between the two strategies remains small because can-do defenders rely mainly on themselves rather than the authorities, so they are less likely to accept the messages anyway.

Threat avoiders. The difference between information and recommendations is much more visible on threat avoiders since they are more likely to accept messages (Figure 5). With the information messages, there are more escapers and less defenders because of danger perception distortion (knowing more fires leads to over-estimating danger), and therefore more damage to buildings. Furthermore, threat avoiders have a lower capability than

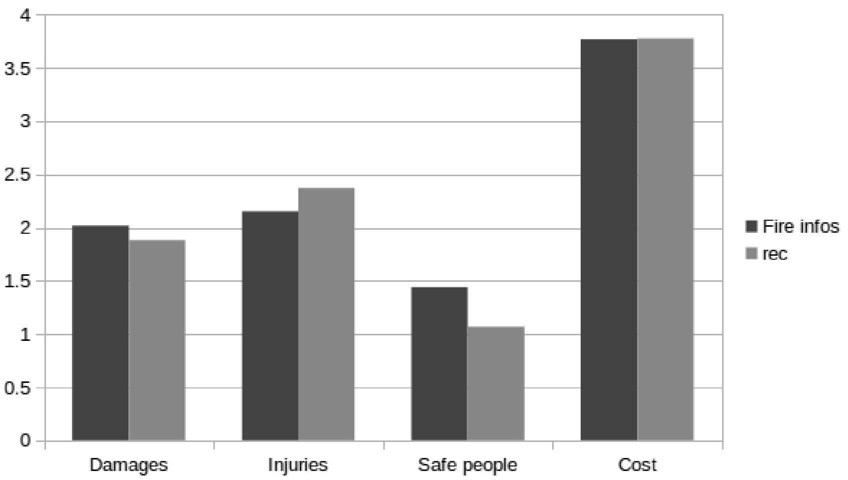

Figure 4. Comparing impact of content-based strategies (information vs recommendations) on Can-do defenders

can-do defenders, their escape will be less efficient so they are more likely to get hurt, leading to more injuries. Recommendations are therefore more efficient than generic information.

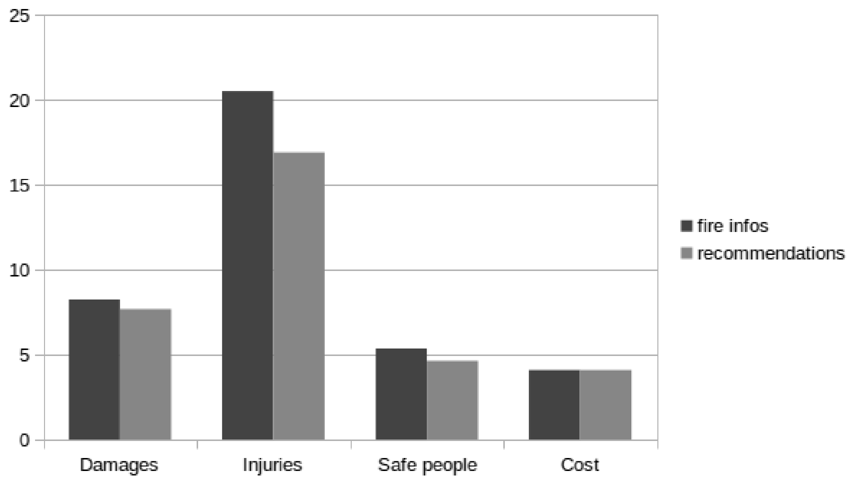

Figure 5. Comparing impact of content-based strategies (information vs recommendations) on Threat avoiders

Scenario 2: impact of accuracy of messages

Can-do defenders. The accuracy of messages has a more significant impact than their content on can-do defenders. Broadcasting is the worst strategy, geographical targeting the best but most costly, and plan-based targeting is a compromise (Figure 6). Contrary to what one might think, message acceptance is not the major factor here (can-do defenders are skilled so they can make good survival decisions even if rejecting most messages). What matters most is the number of escapers: again, broadcasting all fires to all residents leads to over-estimation of danger, encouraging more residents to escape. Can-do defenders are somewhat protected against over-estimation of danger due to their lower trust in messages and higher ability to observe the fires, but we still observed about half of the population escaping and half defending. On the contrary, with geographically targeted communication people are informed only about fires close to them and therefore have a more accurate perception of immediate danger. As a result less residents decide to escape without being in real danger, so they are more likely to protect their home and avoid damage and injuries.

Threat avoiders. Not surprisingly, the most efficient strategies are the same as for Can-do defenders (targeted communication is better than broadcast), even though the values of the indicators (damage, injuries) are much higher here (see Figure 7). This is because threat avoiders are more likely to accept and react to the messages even

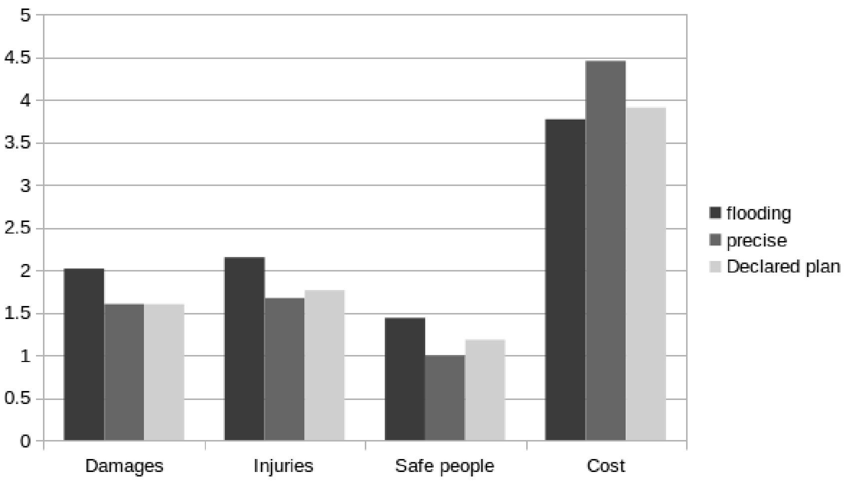

Figure 6. Comparing impact of target-based strategies on Can-do defenders

when not directly concerned (fires too far), and more likely to over-estimate danger due to their lower ability to judge by themselves. As a result we observed much more escapers and less defenders in this population. Therefore less people fight the fires, resulting in more damages to buildings, and the fires grow bigger, injuring more escapers.

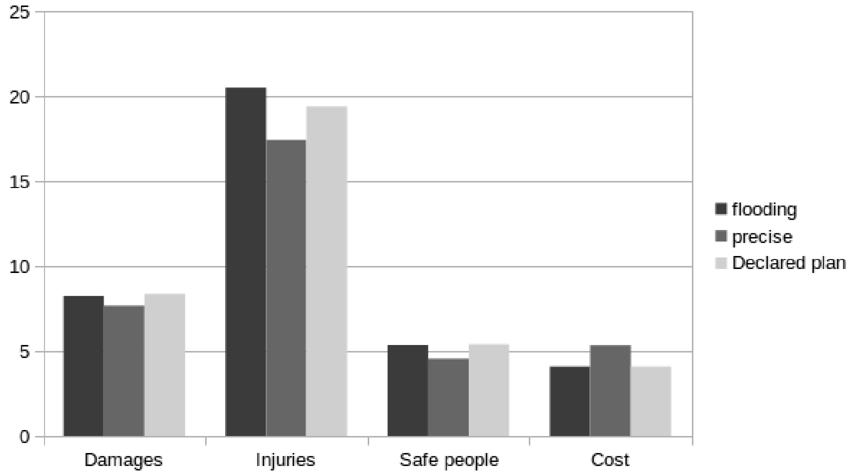

Figure 7. Comparing impact of target-based strategies on Threat avoiders

Scenario 3: impact of shelter communication

The goal here was to compare the efficiency of two opposite strategies: building more shelters but without informing people about them, or relying only a few shelters but advertising a lot about them. Both strategies aim at making sure that all residents know where to escape if needed.

Can-do defenders. We observed no real difference between these 2 opposite strategies on can-do defenders (see Figure 8). Communication is only slightly better but much less costly than building new shelters. This is not really surprising. Can-do defenders are skilled and experienced and therefore know the position of the shelters already (even if there are only few of them) and can reach them easily. Moreover, most of them decide to stay and fight against fires anyway, making shelter-based strategies irrelevant to them. Finally with more defenders, there is less congestion on the roads to the shelters and the fire does not propagate so fast, so the escapers are more likely to reach the shelters uninjured.

Threat avoiders. Shelter-based strategies have a much more differentiated impact on threat avoiders (see Figure 9). The first thing we can notice is the difference in terms of safe people. Threat avoiders have lower abilities to react to

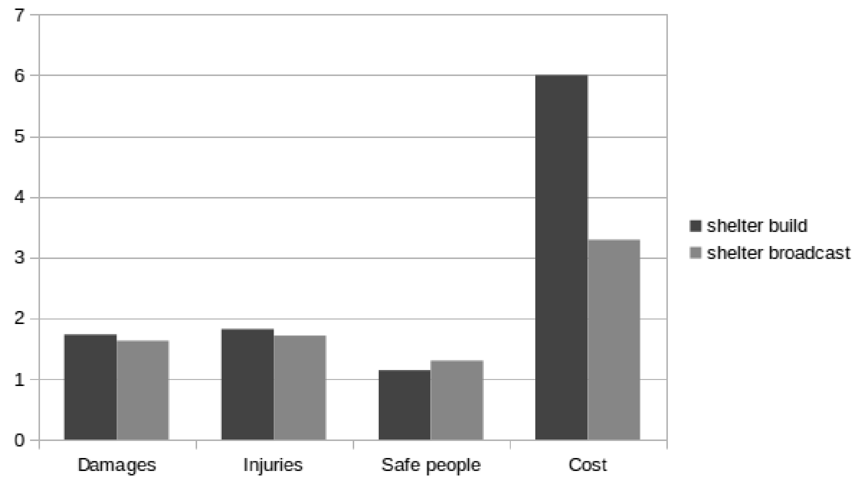

Figure 8. Comparing impact of shelter-based strategies on Can-do defenders

fires, and may not know the position of shelters or not be able to quickly reach them. When building more shelters rather than advertising them, some residents do not know any safe area and just run randomly to avoid fires, leading to more injuries and less safely sheltered people. The longer the simulation time, the bigger the fire grows, and the more randomly running people get trapped. However, the damage is slightly lower in that case as some residents, not knowing where to go, end up sheltering in their own house and defending it. Advertising the existing shelters reduces the time spent on roads looking for one, and therefore the number of injuries incurred by escapers.

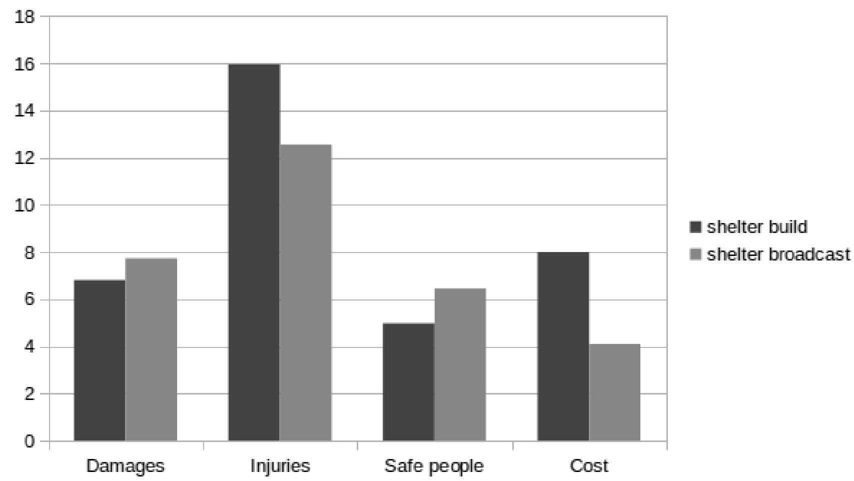

Figure 9. Comparing impact of shelter-based strategies on threat avoiders

Of course these are the two extreme strategies (building only vs communication only) and we expect the best strategy to lay somewhere in the middle, with a balanced compromise of having enough safe areas and making sure everybody is aware of them.

Discussion

Personalisation to the profiles

As expected, communication should be personalised to the different profiles found in the population (or at least to broader categories of defenders vs escapers), in order to provide each resident with information that is relevant and helpful to them without drowning it in a flow of irrelevant messages.

Our results show that the best communication strategy towards can-do defenders is to inform them about fires in their geographical area. Its downside is its high cost (the smaller each target area, the more different messages need to be elaborated and sent), so targeting residents based on their declared plans may also be a good and less costly alternative. Messages about safe areas are secondary for intended defenders and should be used parsimoniously.

Accurate geographical targeting is also better for avoiders (even though more costly), but contrary to defenders recommendations are more useful for them than bare information, as they are not skilled enough to interpret the latter. Moreover, early information about shelters is useful to raise awareness of escape possibilities and trigger earlier evacuation, thus reducing injuries incurred while escaping.

Plan-based targeting

For the plan-based broadcast strategy, we assumed that each resident had previously declared their fire plan (intention to defend or to leave) to the fire authorities. This is not the case in reality (in these scarcely populated areas, the fire brigades might have some information but not necessarily about everybody); however experimenting with this strategy allows us to show what could be done if the population was asked for their fire plan in advance and therefore still provides valuable insight.

Besides, it also shows the interest of indirect communication: global authorities might not know each resident's fire plan when broadcasting messages, but local managers might do. They could act as a filter between the large scale broadcasting and their local residents, receiving all messages and only forwarding the most adapted ones for each resident. Of course this is also a costly strategy, but automation could be investigated.

More experiments needed

A big limitation of our experiments is that they are all performed on a homogeneously profiled population in order to draw relevant results for that population. However in reality, the population is heterogeneous with residents of all 6 profiles listed above, and a continuous range of motivations and abilities. Strategies are yet to be tested on a population with a realistic distribution of these profiles, but we first need to obtain data about what this distribution is in the actual population modelled.

We also tested all strategies independently, while in reality emergency managers may use a combination or sequence of several strategies, for instance broadcasting information and recommendations at the same time. More experiments are yet to be conducted with more realistic combined strategies, possibly in cooperation with emergency managers.

Finally our experiments were quite short: 200 cycles of simulation means about 3 hours of simulated time. In reality these fires can last for days. Longer-term communication strategies thus need to be tested as well, to ensure residents stay out of affected areas, respect possible road blocks, etc.

Simplification

A model always ought to be a simplified version of reality. There are however a number of improvements that could be made in future work to improve the realism of our simulation. Of course the random fire model is the first thing that comes to mind; it should be replaced with a realistic model of fire taking physical and meteorological parameters into account (wind strength and direction, rain, temperature, etc) when computing propagation and growth. Such models already exist (**MHSP2015spark**).

Of more interest to us is the agents involved in the simulation. So far we only modelled residents as autonomous agents, and emergency managers are "played" by the user but can only send messages. It would be very interesting now to also model firemen and their different actions on the field, from fighting the fire to communicating with the population and helping them. The only presence of firemen also has a great psychological impact on residents (**KKRP2014**) which should be modelled.

CONCLUSION

In this paper we described our extension of an existing simulation of the Australian population in bushfires. The underlying simulation was validated against real data obtained mainly from residents' interviews after the 2009 bushfires (**AdGa2017jasss**). Concretely, we enriched the residents model to allow them to handle messages, and modelled several psychological processes that influence this handling. We also added interactive functionality for the user to test various communication strategies on this simulated population. Finally we ran batch experiments to highlight the pros and cons of different possible strategies on different profiles of residents, and deduced some useful insight for emergency managers. However these first experiments were mainly intended as a proof of concept of our simulation, and much remains to be done to improve our simulator and to test more realistic strategies.

In particular, we intend to dedicate some future work to the following aspects. First, we will model a more realistic population, with a heterogeneous distribution of the different profiles, and also with social relationships and attachment between the agents. Second, we will go deeper in the formalisation of cognitive biases (**ArAdDu2017**); here we focused only on a few of them that affect message handling, but many others play a role in disaster reactions; other interesting psychological factors at play in such situations include emotions. Finally the communication model could also be enriched; in particular we want to add more possible message contents (promissives and expressives might be relevant, for instance expressing fear about the situation, or promising that the fires are under control); also we want to more deeply study trust (in the source and channel), its impact on behaviour change, and its dynamic.

It is important to notice that such work is generic and can be applied to different types of disasters. For instance, we have already developed a similar serious game for raising awareness about coastal floods risk (**AdTa2016sprite**). We believe that agent-based modelling and simulation is a great tool to raise awareness and prepare crisis management plans for any types of crisis, be they natural disasters or man-made events.

ACKNOWLEDGEMENTS

This work was partially supported by project AGIR SWIFT.

The role of cognitive biases in reactions to bushfires

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ABSTRACT

Human behaviour is influenced by many psychological factors such as emotions, whose role is already widely recognised. Another important factor, and all the more so during disasters where time pressure and stress constrain reasoning, are cognitive biases. In this paper, we present a short overview of the literature on cognitive biases and show how some of these biases are relevant in a particular disaster, the 2009 bushfires in the South-East of Australia. We provide a preliminary formalisation of these cognitive biases in BDI (beliefs, desires, intentions) agents, with the goal of integrating such agents into agent-based models to get more realistic behaviour. We argue that taking such "irrational" behaviours into account in simulation is crucial in order to produce valid results that can be used by emergency managers to better understand the behaviour of the population in future bushfires.

Keywords

Multi-agent modelling, social simulation, cognitive biases, BDI paradigm, Victoria bushfires

INTRODUCTION

The bushfires in Victoria, Australia, on February 7, 2009 (also known as Black Saturday) caused 173 deaths and 414 injuries. Most of the victims were badly prepared to face a fire of such severity and were caught out by surprise (*Victorian 2009 Bushfire Research Response Final Report* 2009; Thornton, 2010). The population's behaviour before and on that day is still not fully understood and is sometimes referred to as being irrational (*i.e.* people did not behave according to what would objectively be in their best interests). This was surprising since most of the victims had lived in high fire-risk areas for many years and were aware of the safety issues. The emergency services expected most of the population in the affected area to evacuate before the fire arrived. This was not the case, highlighting a problem with Victoria's crisis management plan, including the communication with the public.

Agent-based modelling and simulation (ABMS) is a technique from Artificial Intelligence (AI) that provides us with a tool to model human behaviours and to test the effect of several parameters. By specifying the attributes of each individual (*e.g.* stress, exhaustion, knowledge, and also fire plans, etc.) at the micro-level, we can observe the overall behaviour during fires at the macro-level (*e.g.* the number of people who escape the fire, number of deaths). The proposed approach is to apply ABMS to the field of crisis management in order to improve evacuation plans. The application of such a technique has been used previously (Pan et al., 2007; Cardon, 1998; Dugdale et al., 2010) and it is still a very active area of research. One of the most recurrent issues is the level of complexity of the agents; should humans be modelled with simple rules, following the KISS (Keep It Simple, Stupid) principle advocated by (Axelrod, 1997), or is it better to create more complex agents that are closer to reality, following the KIDS (Keep It Descriptive, Stupid) principle advocated by (Edmonds and Moss, 2004)?

The specific difficulty of choosing an agent's level of complexity when trying to model complex human-like agents has already been discussed (Adam and Gaudou, 2016; Dugdale, 2010). These authors advocate that an agent trying to mimic human behaviour can not be efficiently modelled with simplistic rules. They concluded that the Belief-Desire-Intention (BDI) agent architecture offers some appreciable features such as: "adaptability, robustness, abstract programming and the ability [for agents] to explain their behaviour."

These features are an undeniable asset in order to model and understand the behaviour of the Victorian population during a fire event. Nonetheless, as stated by (Norling, 2004), the BDI architecture does not capture many aspects of human behaviour and reasoning. It therefore needs some additional work in order to better mimic human behaviour and serve as a grounding model for social agents (Dignum et al., 2014). Throughout this paper we argue that part of this additional work should deal with cognitive biases. We advocate that they play an important role in human behaviour and need to be taken into account when developping a model, especially during crisis situations.

Cognitive biases are known to be mechanisms widely used by the human brain and which are sometimes unadapted to the situation, leading to mistakes or inaccuracies. Cognitive biases are believed to be found in any strategic decision process (Das and Bing-Sheng, 1999). They are also found in decision-making processes in uncertain situations (Tversky and Kahneman, 1974). Strategic decision making and deciding under uncertainty are typical cognitive reasoning mechanisms undertaken by people in crisis situations such as bushfires (Adam et al., 2015). In addition, crisis situations impose a time constraint on reasoning. Therefore strategic decision making and reasoning with imperfect information in limited time are common, making cognitive biases more likely to happen.

Our overall goal is to build a BDI model (Adam et al., 2016) of human behaviour in crisis in order to improve social simulations by better mimicking human behaviour. In light of the information above, we can see that cognitive biases strongly affect human behaviour during crisis situations. Specifically, they can be the cause of biased perceptions and/or judgements, leading to dangerous behaviours for oneself and reliant others. As a result, we claim that their integration in agent models will improve social simulations of crisis situations. The first goal of this paper is to prove this impact of cognitive biases in crisis situations by identifying some well-known cognitive biases in the victims' testimonies of the Black Saturday event. The second goal is then to formalise these cognitive biases in terms of BDI algorithms, in order to make a first step towards their integration in an agent model for social simulation.

Similar work of integrating cognitive biases in a model has already been performed in the domains of health (Voinson et al., 2015) and national defense (Kulik and Davis, 2002). However none of these models use the BDI paradigm, which is central in our approach.

The following section presents our data set and the methodology used for data extraction. A presentation of the BDI paradigm follows, with an explanation about the required architecture to implement our BDI model of cognitive biases. We then describe our formalisation of three cognitive biases in the form of algorithms, and illustrate these biases with examples from our data set. Finally the conclusion discusses limits of this work and compares our approach to the literature.

FINDING AND EXTRACTING DATA

The first task in order to ascertain whether or not cognitive biases played a part in Black Saturday victims' behaviour is to find relevant data. Black Saturday was the worst fire event Victoria ever suffered, consequently casualties and material losses were severe. As a result the state of Victoria created several work groups to understand what happened. Two of them are the *2009 Victorian Bushfires Royal Commission* (VBRC) and the *Bushfire Cooperative Research Centre* (Bushfire CRC). These groups drew data from what they could find (*e.g.* flora, fauna, victims interviews stating their feelings and memories, police hearings, and general state of the land) and wrote detailed reports (*Victorian 2009 Bushfire Research Response Final Report* 2009; *Final report* 2009). The data contained in these reports were extensively used in the scope of this work.

Post Black Saturday reports

Particular attention has been given to the fourth volume of the VBRC final report (*Final report - vol. IV : the statements of lay witness* 2009). It contains 100 statements from lay witnesses of the Black Saturday events, ordered alphabetically by the witness' name. Statements are heterogeneous in terms of content and source (*e.g.* testimonies from firefighters who helped during the events, information about the physical and mental state of victims from nurses who came later to help, testimonies of individuals focusing on their struggle with the insurance companies, testimonies of Black Saturday events from family members who suffered a human loss, and detailed testimonies of the day from people who survived the events.) They are narrative transcriptions of oral statements with attached evidence (*e.g.* photos, maps). Statements are divided into numbered paragraphs and attempts have been made by the interviewer to create consistent sections throughout the statements when possible (*e.g.* fire plan, the property, views previous to Black Saturday, views during Black Saturday).

The bushfire CRC Final report (*Victorian 2009 Bushfire Research Response Final Report* 2009) has also been studied in depth. Sections about human behaviour helped in the formulation of the hypothesis relative to the importance of cognitive biases (*e.g.* by highlighting the importance of environmental cues in alerting Victorians and thus the unconscious concealment of other cue types). This report was also used for the statistics that it contains about the Victorians intentions and actions during Black Saturday. These statistics were compared to those found in a 2010 survey about the behaviour that Victorians would adopt on Code Red (*i.e.* worst conditions for bushfires) days (Research, 2010), in order to form a more accurate idea of how Black Saturday affected the Victorians representations of a fire event. This second report concludes by stating that only 3% of Victorians would leave on a Code Red day, even though they aware that authorities' advice is to leave early on those days. Only 15% would stay and defend. This leaves 82% of Victorians in a "wait and see" state, which is the reason why so many Victorians were trapped during Black Saturday fires.

More on cognitive biases

Cognitive bias is a broad and poorly defined concept that encompasses roughly a hundred effective cognitive biases (see (Benson, 2016) for a large but non-exhaustive list). Some are well known, while others are merely suspected. Some are known to be groups of cognitive biases (*e.g.* the Risky Shift Phenomenon is a cognitive bias discovered in 1960, stating that decisions made as a group are less conservative than decisions made by the average group member (Shaw et al., 1976); this can in fact be caused by other, more specific, cognitive biases). Some are more concerned with affection (loving) (Reyna and Brainerd, 2008; Kahneman and Frederick, 2002))than cognition (thinking). Nonetheless all cognitive biases have two things in common.

First they all serve a common purpose. They help the brain to do its work faster and/or longer, often by using low-cost mechanisms to make decisions or to filter the amount of information gathered by the brain at any time. For example, the "Attribute substitution" mechanism enables us to give the answer to an easy question when confronted with a difficult one (Kahneman and Frederick, 2002) (*e.g.* when asked the question "How far is the mountain ?", if one does not know the answer, one will answer the question "How blurred is the mountain compared to the ambient haziness?" instead.)

Second they can be the source of mistakes. Since their purpose is to help the brain to make a decision faster or to ignore information, it is not surprising to find that these biases can sometimes lead to inaccurate decisions. Nonetheless it is worth noting that despite the denomination of "cognitive biases" inaccuracies seem to occur only in specific, rather uncommon, situations (Pohl, 2004).

Examining the testimonies

Cognitive biases are a wide and heterogeneous family; hence the goal was to find out more about which specific cognitive bias could be found in Black Saturday testimonies. For this purpose we went manually through 30 of the testimonies gathered by the VBRC. Since little attention has been given in the past to identifying cognitive biases in testimonies of populations during crisis situations, no tool exists yet to automatically analyse such interviews. Therefore a new method had to be designed.

Half of testimonies were ignored, since they could not be of any help (*i.e.* the interviewee was not talking specifically about the Black Saturday events). The other half were searched for situations where survivors or deceased people put themselves at risk. Each such dangerous situation was isolated and we looked for the decision which could have led to it. Then this decision was interpreted according to a set of well-established cognitive biases. For example Edward Cherry is in a dangerous situation (p.16) when outside of his house during an ember attack (ember attacks precede the fire front, which is the most dangerous part of a bushfire event). He took the decision to water the roof of his house a bit longer , while his wife was "shrieking at him to come inside", before suddenly becoming aware that everything around him was on fire. This is likely to be caused by an Optimism bias (*i.e.* a cognitive bias which lead people to under-estimate the risk of a given situation they are involved in compared to the estimation they would make if not involved). It is worth noting that at least one cognitive bias or set of cognitive biases potentially leading to each dangerous situation were found. Sometimes several unique sets were found.

In the following example, several cognitive biases could led to the decision. Brett Savage in Michelle Buntine's testimony (*Final report - vol. IV : the statements of lay witness* 2009) evacuates his property after having tried to defend it (p.31-32). Earlier, he did not listen to his partner in life, Michelle Buntine, when she told him repeatedly to evacuate (p.26, 28). He also received a call from a friend who is a firefighter and who, in order to make him leave, explained to Brett what would happen during the next hours if he stayed (p.29-30). He stayed and fought the fire for some time before having to evacuate during the fire event.
In terms of cognitive biases it is hard to detect what played a part in Brett's decision to stay and fight. It could be

the Conservatism bias (*i.e.* a slow update of his beliefs that he would be safe while defending his property), the Semmelweis Reflex (i.e he clung to his belief, even with compelling evidence that it was false), an Anchoring effect (*i.e.* he was committed to the idea to defend his house), the Optimism bias (*i.e.* he though he was not at risk in this situation while someone else would have been) or the Overconfidence effect (*i.e.* he considered his beliefs as more accurate than the ones from his partner and friend). The most simple, robust, and consistent with the psychology literature sets were kept. However, we acknowledge that some may have been missed.

Retained cognitive biases

The use of our method revealed that some types of cognitive biases were found more often than others: biases about 1) beliefs (*i.e.* biases acting in favour of, or against, the update of a previous belief), 2) affect (*i.e.* biases favouring the option in which something one likes could be preserved over the option in which one is in a safe place) and 3) bad probability estimation (*i.e.* some options are seen as far more/less probable than they really are).

Three cognitive biases were chosen, according to this finding and for two other reasons: biases chosen are relevant to each other (*i.e.* the same tools can be used to model the three of them, and their interaction creates a logical model of information processing); they are easily adaptable to the BDI paradigm, which makes an extensive use of the notion of belief. The three biases are: 1) The Neglect of Probability bias, which belongs to the bad probability estimation category, 2) the Semmelweis Reflex and 3) the Illusory Truth effect. The last two biases belong to the belief updates category. No cognitive bias found in the affection category satisfied the conditions and so have not been included.

PROPOSED BDI MODEL OF COGNITIVE BIASES

The BDI paradigm

The BDI paradigm describes agents in terms of their mental attitudes (Beliefs, Desires, Intentions), which are "folk psychology concepts that straightforwardly match human reasoning as people understand it, making the models easier to design and to understand" (Adam and Gaudou, 2016).

1. **Beliefs** represent an agent's knowledge about the world (*e.g.* road 45 is blocked, ember attacks precede the fire front).
2. **Desires** are the goals of an agent, *i.e.* their preferred states (*e.g.* be close to one's children). They can be inconsistent (*e.g.* during an ember attack, the agent might both want to defend its house and to flee the fire). Choosing between desires is the role of a reasoning engine (Norling and Sonenberg, 2004), that remains to be chosen in this work.
3. **Intentions** are what an agent is committed to do. They are basically refined, practical desires. They have to be consistent with each other, and should not be dropped easily. The agent usually has a library of plans (sequences of actions) allowing it to achieve its intentions.

Required agent model

In this section we describe the required minimal architecture for an agent to be able to implement the cognitive biases. We do not provide a conceptual agent model, but give a minimal set of requirements for an agent architecture to be able to implement the cognitive biases algorithms in this paper.

- A belief operator with associated subjective probability, ranging from 0 (certainly wrong) to 100 (certainly true). The addition of subjective values of a belief and its opposite sum to 100. A belief with a probability of 50 means that the agent is completely unsure.
- A belief base that stores beliefs.
- Psychological attributes, such as level of risk aversion.
- A table of occurrences of received information (counting how many times the same information have been received)
- A function **getBeliefProbability (Belief φ)** that returns the probability of a given belief.

- A function **saveBeliefProbability (Belief φ, Number α)** that updates the probability of a given belief in the agent's belief base.
- A function **incrementNumberOfOccurrences(Information φ)** that increments by 1 the number of times a given information has been gathered by the agent.
- A function **getAcquiredInfoOccurrences(Information φ)** that returns the number of times the agent has gathered a given information.
- A function **acquireBelief(Belief φ, Number α)** that saves a given belief and associated probability to the agent's belief base.
- The functions **dramaticallyIncreaseBeliefProbability (Belief φ, Number α)** and **decreaseBeliefProbability (Belief φ, Number α)** that modifies the probability of a given belief.

This minimal required architecture may be provided by PLEIAD (an affective agent coded in Prolog (Adam and Lorini, 2014)) or by GAMA (an agent-based simulation platform (Grignard. et al., 2013) recently enriched with a BDI architecture for the agents (Taillandier et al., 2016)).

MODEL OF THE THREE BIASES

In this section we provide a generic model of three cognitive biases using the architecture described above. Only pseudo-code is described so as not to commit to a particular implementation language.

Neglect of Probability

We formalise the Neglect of Probability bias in algorithm 1. We begin by explaining what we mean when using the expression "are perceived to be...", then we detail this bias and its mechanisms. Uses of the expression "are perceived to be ..." in the formalization of the Neglect of Probability bias are shortcuts for two statements.

- The consequences implied by this belief could be dire or extremely favourable (*e.g.* for agent A believing that road R is on fire implies that he could not reach his home, this will leave his home unprotected and at risk of probable burning; which is a dire event).
- The risk aversion or risk seeking value of the agent makes him perceive the consequences as extremely favourable/unfavourable, as described in (Kahneman and Tversky, 1979).

The Neglect of Probability bias is composed of three mechanisms. Two of them target low probability beliefs while the third one targets high and medium probability beliefs.

- The first mechanism (described in (Reyna and Brainerd, 2008)) is a way to ignore what is perceived both as unlikely to happen and as having no consequences. It is formalized on lines 9-10 of algorithm 1. It reads: if the agent estimates something only has a low chance of being true and has no consequences, then the agent considers it as false.
- The second mechanism (described in (Sunstein and Zeckhauser, 2010)) is a way to anticipate an event that would greatly impact one's life and thus enables one to prepare for it. It is formalized on lines 11-12 of algorithm 1. It reads: if the agent estimates that something has a low chance of being true but either desires or dreads it, then the agent considers that it has a substantial chance of being true.
- The third mechanism (described in (Tversky and Kahneman, 1983; Kahneman and Tversky, 1979)) reduces the perception of high and medium probabilities. It is formalized on lines 13-14 of algorithm 1. It reads: if the agent estimates something has a high or medium chance of being true, then the agent under-estimates its probability of being true.

Algorithm 1 Pseudo-code for the Neglect of Probability bias

```
procedure updateBeliefProbability (info, perceivedProbability )
    ancientBeliefProbability ← getBeliefProbability (info)
    newBeliefProbability ← ancientBeliefProbability + perceivedProbability

    if newBeliefProbability > 100 then
        newBeliefProbability ← 100
    end if

    if newBeliefProbability is small and consequences are not perceived to be dire and consequences are not perceived to be extremely favourable then
        newBeliefProbability ← 0
    else if beliefProbability is small and (consequences are perceived to be dire or consequences are perceived to be extremely favourable) then
        newBeliefProbability ← dramaticallyIncraseBeliefProbability (info, newBeliefProbability)
    else   # newBeliefProbability is medium or high
        newBeliefProbability ← decreaseBeliefProbability (info, newBeliefProbability)
    end if
    saveBeliefProbability (info, newBeliefProbability)
end procedure
```

Alice Barber

Alice Barber is a woman who survived the events but was injured. She lost her house. No children or partner in life are recorded. She likes to garden and therefore her house is surrounded by vegetation. Prior to the event she possessed a fire plan, *i.e.* go to a place that she scouted earlier and identified as a potential shelter, and a fire plan trigger, *i.e.* act according to the fire plan as soon as the power is cut in the house.

- **The dangerous situation** is the fact that she lives in a high risk area with a weak fire plan trigger.
- **The decision leading up to the situation** is to choose a weak fire plan trigger.
- **The Neglect of Probability** is highlighted when she testifies about her mental attitude: "what will happen, will happen" (p. 7). She does not want to bother herself with costly fire preparations and does not consider a fire event as dire. Plus she has good reasons to believe that her fire plan trigger is good. Thus neglecting the probability of such an event.

This situation could be modelled by one agent as follows:

- **Beliefs:** Fire plan will be triggered before a fire is detected (100)
- **Desires:** Be safe, Be close to the house
- **Intentions:** Stay close to the house until the fire plan triggers, then follow fire plan
- **Risk aversion:** Low

Andrew Paul Trenwith Berry

Andrew Berry is a married man who survived the events with his wife, Nicole, and his father. Although Andrew and Nicole made relevant decisions regarding this case, they lost their house. Prior to the events Andrew possessed a house with a sprinkler-based defense system (considered as the best anyone can do (p. 14) by some Country Fire Authority (CFA) members) and a bunker that was close to the house that was large enough to accommodate a dozen people. The fire plan was to stay and defend. The family also experienced fire in 2006. This experience raised their risk aversion. This example is reversed, since the Neglect of Probability saved the family.

- **The safe situation** is the fact that Andrew and Nicole were able to shelter inside the bunker while their house burnt.

- **The decision leading up to the situation** is to have a the bunker built in the yard, despite a good house defense system.
- **The Neglect of Probability** underlies the decision of building the bunker. The 2006 fires raised Nicole and Andrew's father risk aversion. Thus the probability associated to the belief of experiencing a fire strong enough to threaten their lives while sheltered in their apparently well-defended house were overestimated (weather conditions during Black Saturday were unique and very unlikely).

This situation can be modelled with a single agent as follows:

- **Beliefs:** House is safe (60), Bunker is comfortable (0), Bunker is safe (70)
- **Desires:** Be safe, Be comfortable
- **Intentions:** Stay safe in the house before and during the fire front, then defend it. If not safe in the house, go to the bunker.
- **Risk aversion:** High

Fiona Wallace

Fiona has a partner in life named Heather and they both survived Black Saturday. No children are recorded as being involved. They are both Victorians, living in low fire-risk areas. They went to a Bed and Breakfast (B&B) hostel located in a high fire-risk area during Black Saturday. They both were aware of the warning issued by the authorities during the days prior to Black Saturday.

- **The dangerous situation** occurs when the fire reaches the B&B they are staying in and they have to defend it.
- **The decision leading up to the situation** is the decision to go on a trip in a high fire risk area while knowing about the hazardous weather conditions.
- **The first Neglect of Probability** underlying this decision occurs when Fiona and Heather hear the news about the weather: "the comparisons to Ash Wednesday emphasised the severity of the risk and we knew that it was going to be an extremely bad fire danger day." (p. 3). The probability of a fire being high in the information received is being neglected and is considered as medium rather than high.
- **The second Neglect of Probability** underlying this decision occurs when Fiona and Heather reason about the probability of having their particular B&B being attacked by fire in such a large area: "We reasoned that even when there is a major fire, a huge amount of rural Victoria does not get burnt." (p.4). This probability ends up being low. Since their aversion to risk is also low the probability associated to the belief of being caught in a fire event is neglected.

This situation can be modelled with a single agent, as follows (beliefs in italic can be omitted if a reasoning engine allows agents to build their own beliefs this way):

- **Beliefs:** B&B is relaxing (80), B&B is prone to fires (45), *B&B will experience a fire event during the trip (0)*
- **Desires:** Be safe, Be relaxed
- **Intentions:** Go to a safe and relaxing place.
- **Risk aversion:** Low

Semmelweis Reflex / Belief Perseverance

The Semmelweis Reflex, also called Belief Perseverance, is a cognitive bias in which people cling to their beliefs even when they face proofs they are not true (Anderson, 1983). The Semmelweis Reflex is formalized in algorithm 2, based on an explanation given in (Savion, 2009); stating that a certainty is harder to update than a belief one thinks is only probable. One of the ways to "overcome" this bias has been suggested (p. 85 of (Savion, 2009)). This has been modelled in order for the agents to eventually update their certainty. The way to overcome the bias is based on the repetition of information (*e.g.* if an agent is certain of φ it needs to get the information $\neg\varphi$ a certain number of times before it will be able to update its former certainty). This is consistent with the Illusory Truth formalization.

Algorithm 2 Pseudo-code for the Semmelweis Reflex

```
function testForSemmelweisReflex(info)
    if getBeliefProbability (info) = 0 and acquiredInfoOccurrences(info) is not enough then
        return True
    else  # getBeliefProbability (info) > 0 or acquiredInfoOccurrences(info) is enough
        return False
    end if
end function
```

John Benett

John lives alone, he survived and, with other people, he successfully defended his house. During the whole afternoon, John felt a North wind blowing. At 3pm he received a call from a friend, warning him that a fire was coming from the West to his property. John ignored this warning. Later, he saw people driving dangerously near his property. He did not pick up on these cues either.

- **The dangerous situation** occurs at 5pm when a fire caught John by surprise. It came from the West while a North wind was blowing.
- **The decision leading up to the situation** is to ignore cues going against his belief that no fire could come from the West while the wind was blowing from the North.
- **The Semmelweis Reflex** underlying this decision prevents him from considering cues contrary to his belief that the fire will come from the North, as he states: "I thought that the North wind would prevent the fire from reaching Kinglake West and that it would direct it somewhere else." (p. 7)

This can be modelled in one agent as follows:

- **Beliefs:** House is safe (100), Fire goes in the same direction as the wind (100)*, Fire will come from [current wind direction] (100)*
- **Desires:** Be safe, Defend the house
- **Intentions:** Monitor *[current wind direction]* side of the land to gather environmental cues about an approaching fire, then proceed to defend the house.

Jim Baruta

Jim is married but his wife was not involved in the events. He survived but lost his house.

- **The dangerous situation** occurs at 5pm when when he drove on a road during a fire event (p.15).
- **The decision leading up to the situation** is to to keep driving even though he saw smoke and fire spots on the road.
- **The Semmelweis Reflex** occurs after at least one other cognitive biases was triggered (*e.g.* Optimism Bias) to build a certainty about the fact that he would be safe travelling home even though he knows he should not be doing it: "[in case of fire] you can't get on the roads, that is the last thing you should do" (p. 10). The Semmelweis Reflex prevents him considering cues that are contrary to his belief that he will be safe on the road.

This can be modelled in one agent as follows:

- **Beliefs:** The road home is safe (100), Do not be on the road during a fire event (80)
- **Desires:** Be safe, Defend the house
- **Intentions:** Go home then proceed to prepare and defend the house.
- **Risk aversion:** Extremely low

Illusory Truth

The Illusory Truth bias was shown for the first time in 1977 (Hasher et al., 1977) and has proven to be quite robust. Its effect is straightforward: the more one hears some information, the more one is inclined believe that the information is true. The Illusory Truth effect also ignores prior knowledge (Fazio et al., 2015), which makes it easier to formalize. It is formalized in algorithm 3, on lines 8-12. It reads: if the current agent already possesses a belief relative to the last information it gathered, then reinforce the belief according to the credit it puts in this information, multiplied by the number of times it gathered it. This has been implemented regarding *processing fluency* (Fazio et al., 2015). According to the author the Illusory Truth would come from the fact that repetition makes information easier to understand. Processing fluency states that the easier something is to understand the more truthful it appears. In our algorithm, on line 10, the probability associated with an information perceived is linked to the number of times this same information has already been perceived.

Algorithm 3 Pseudo-code for the Illusory Truth effect

```
1:     # φ is an information given by the environment to an agent
2:  info ← perceive(φ)
3:  perceivedProbability ← perceiveProbability (φ)
4:  incrementNumberOfOccurrence(info)
5:
6:  if not hasBelief(info) then
7:      acquireBelief(info, perceivedProbability )
8:  else   # hasBelief(info)
9:      if not testForSemmelweisReflex(info) then
10:         illusoryProbability ← perceivedProbability * acquiredInfoOccurences(info)
11:         updateBeliefProbability (info, illusoryProbability)
12:     end if
13: end if
```

Peter Ross Brown

Peter Brown is a married man with three children (aged 20, 18 and 16). He lives with his wife and children in their own house with a pool. The pool is intended to serve as a water tank in case of a fire event. During Black Saturday Peter's oldest child was away. Peter also listened to ABC radio during the entire day. The whole family survived the events but lost the house.

- **The dangerous situation** occurs when the family members are gathered in and around the pool and the fire unexpectedly strikes.
- **The decision leading up to the situation** is for the family not to evacuate and not to prepare the house before the fire arrived. Peter was trying to connect the fire pump to the pipes when it did.
- **The Illusory Truth** makes Peter believe in the accuracy of ABC announcements, since the ABC announcer repeated that they provided the most up-to-date source of information concerning the bushfire (p. 16). Next Peter reasons that since there was no warning from ABC for his area it means that his house and family are not threatened.

This situation can be modelled with a single agent as follows:

- **Beliefs:** ABC Radio provides up-to-date information (100)*, No fire is detected in my area (100)*
- **Desires:** Be safe, Defend the house, Do not prepare the house if not needed
- **Intentions:** Monitor for a threat by listening to the best radio channel found and looking at the environment, proceed to prepare the house if a fire is detected.
- **Risk aversion:** Medium

Michael Halls

Michael is the father of Natasha Davey. His daughter died during the Black Saturday along with her family. The family was sheltering inside their house, which had been well prepared and was defended by Natasha's husband.

- **The dangerous situation** occurs when the family is in the house while a fire is coming.
- **The decision leading up to the situation** is to stay and defend the house.
- **The Illusory Truth** makes Natasha believe that a well-prepared and defended house is a safe place in case of a fire event. Michael Halls testifies that his daughter's family has been reading brochures, comparing what they were going to do in the face of a fire to what their neighbours were going to do (which was more), and went to CFA meetings (p.7 - 13, 29). Furthermore, the CFA brochures they consulted implied that if one is well prepared, one has nothing to fear from a fire (p. 38, "Why does the bushfire guide show pictures of children protecting a property?").

This situation can be modelled with a single agent as follows:

- **Beliefs:** The house is well prepared (80), I can defend the house (80), My husband can defend the house (80), A well-prepared and defended house is safe (100), The house is comfortable (80)
- **Desires:** Be safe, Have the children in a safe area, Have the children being comfortable
- **Intentions:** Monitor fire threat from inside the house. In case of a fire event, shelter in the house then defend it.
- **Risk aversion:** Medium-High

CONCLUSION AND FUTURE WORK

Psychology and cognitive science related works show that cognitive biases affect human behaviours in crisis situations, where uncertainty or stress factors are present. Examples of individuals putting themselves, their friends or their family at risk by acting in a way that was not anticipated by decision-makers have been extracted from a concrete set of data. These behaviours were then connected to cognitive biases. Three specific cognitive biases have been formalized into algorithms, which are consistent with their related bias description in the literature. We argue that implementing these algorithms in BDI agents can make them more realistic by addressing some of BDI core issues (as identified by (Norling, 2004)) in terms of 1) decision making, 2) inaccuracies and 3) situation awareness of agents.

This work though should be considered preliminary. We provided algorithms to ease implementation of the biases, which constitutes a good basis for a computational model, but we have not implemented and tested them yet. These algorithms, although not yet implemented constitute a good basis for a computational model and ease implementation.

The methodology used to find occurrences of cognitive biases in our data set should also be treated as a work in progress. Since it is not based on any scientifically-grounded model of cognitive biases (we could not find any both exhaustive and reliable), it relies on disparate scientific evidence. Results are therefore based on a subjective interpretation of the testimonies.

Scarce examples of models integrating cognitive biases can be found. This work can be compared to two of them. The first is in the field of national defense (Kulik and Davis, 2002), while the other is in the field of health (Voinson et al., 2015).

The national defense model aims to predict a target's reaction to "Effect-Based Operation" (EBO) (*e.g.* the 9/11 events in the U.S.). It is based on a "Synthetic Cognitive Modelling" (SCM) approach, which takes several factors into account and gives probabilistic results. While their work aims to predict how an EBO would affect a target, we are trying to understand why a population reacts the way it does in a crisis situation. This explains the use of different paradigms. We make use of a white box (*i.e.* something we can see into) paradigm (BDI), in order to explain behaviours. Eventually we would like to build a serious game to experiment with the impact of different factors on the population. This work in national defense uses a black box (SCM) paradigm, looking only at inputs (data), and outputs (behaviours). Their approach of cognitive biases also differs from ours, since they do not offer any framework to integrate identified cognitive biases or mind mechanisms in their model.

The model in the health field is based on mathematical functions and thus uses a white box approach. It aims to help understanding why individuals in developed and developing regions can be reluctant to vaccination, even though "vaccination has greatly reduced the burden of infectious diseases worldwide". The authors advocate that models should not assume individuals to be rational, which bring our work close to theirs. This irrationality is modelled using using a standard model made for capturing the disease transmission process, augmented by a belief model and two functions representing two distinct cognitive biases. However, the belief model is far simpler than the one implemented in BDI and only takes into account two parameters for each individual (epidemiological status and opinion). Our work is closer to this model than to the previous one, even though this model is mathematically based. However this work uses the KISS principle, in which things are as simple as possible, while ours is more descriptive.

Two areas for future work are planned. First, more work is needed on the conceptual side of our cognitive biases model in order to refine how it integrates with the underlying formal semantics of BDI agents. Second, we want to implement and test the biases that we have presented in order to validate our hypothesis. The implementation may then be enhanced in several ways. The Belief Perseverance Effect implementation will be complemented by the addition of other ways to overcome the fallacy as described in (Savion, 2009), along with a way to slow down the belief-updating process (*i.e.* Conservatism bias). The Illusory Truth Effect will be widened by the implementation of the processing fluency mechanism. In a more general way, this work would benefit from the formalisation of trust, which can affect perceived probabilities. The affective heuristic (Slovic et al., 2002) will also be integrated, along with work on an "affective weight" agents give to their environment. This will help us understand how agents integrate and contextualize objects in the world.

ACKNOWLEDGEMENTS

This research was funded by the University Grenoble-Alpes through AGIR project SWIFT (2016-2019), and by Grenoble Pôle Cognition (2017).

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Tracking urban resilience to disasters: a mobility network-based approach

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ABSTRACT

Disaster resilience is gaining increasing attention from both industry and academia, but difficulties in operationalizing the concept remain, especially in the urban context. Currently, there is scant literature on measuring both spatial and temporal aspects of resilience empirically. We propose a bio-inspired quantitative framework to track urban resilience to disasters. This framework was built upon a daily human mobility network, which was generated by geolocations from a Twitter Streaming API. System-wide metrics were computed over time (i.e. pre-, during and post-disasters). Fisher information was further adopted to detect the perturbation and dynamics in the system. Specifically, we applied the proposed approach in a flood case in the metropolis of São Paulo. The proposed approach is efficient in uncovering the dynamics in human movements and the underlying spatial structure. It adds to our understanding of the resilience process in urban disasters.

Keywords

Fisher information, human mobility, network analysis, Twitter, urban resilience

INTRODUCTION

Due to the increasing risk, frequency, and intensity of natural disasters caused by climate change, disaster resilience has gained momentum in both academic and policy discourse (Meerow, Newell, and Stults, 2016). Building urban resilience emerges as a critical agenda due to rapid urbanization, and extensive interconnected infrastructure systems in urban areas (Cutter et al., 2014). Resource dependencies of cities on surrounding or other areas can incur cascading impact on their dependent areas, and pre-existing urban stressors can aggravate the effects of climate change (Cutter et al., 2014). We lack a unified definition of disaster resilience. However, one that contains many characteristics of disaster resilience is from the National Academy of Sciences (NAS): "*the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events*" (Cutter et al., 2012). Resilience in the disasters research field, though overlapped with concepts of vulnerability and robustness, has a different emphasis on the dynamic process of adapting or recovering from natural disasters or extreme events (Hufschmidt, 2011; Zhou et al., 2010). Tailored to the urban context, disaster resilience should highlight both temporal and spatial scales. These scales can be used to describe its capability of maintaining or returning to desired functions, adapting to change, and transforming systems after perturbations (Meerow et al., 2016) to address the complexity and dynamics of cities.

Currently, it is still impossible to precisely predict the climate extremes in terms of spatial distribution and temporal evolution, regardless of their increased intensity or frequency (Linkov et al., 2014). These unknowns require redoubling operational efforts in building resilience. We need rigorous measurements to guide what and how to measure success (Garmestani et al., 2013; Spears et al., 2015). This is important because operationalizing the concept of urban resilience to disasters has been difficult to apply and manage; moreover, inappropriate usage of the term can bring significant negative impacts when guiding responses to natural disasters of urban systems (Angeler and Allen, 2016). However, the multiplicity and vague definitions of resilience increase difficulties to measure resilience. Cities, as complex systems, do not lend themselves easily to measurement. It is also difficult to access high-quality data during disasters to support quantification.

Fortunately, an array of approaches for assessments and quantitative measures of disaster resilience have been developed (Quinlan et al., 2015). Some conceptual frameworks have been proposed to quantify disaster resilience in a deterministic way for decision making in different scenarios, e.g., Zobel (2011), Zobel (2014), Zobel and

Khansa (2014), and MacKenzie and Zobel (2015). Most of them were based on the relationship between an initial impact of a disaster event and subsequent time to recovery. Some focused on empirical quantifications (Cimellaro et al., 2010; Pant et al., 2014; Cutter et al., 2014; Lam et al., 2015) from a specific perspective such as facility, economy, social, policy etc. Some of these studies have examined the dynamic nature of resilience over time, especially for the recovery process (e.g. Pant et al., 2014; Zobel, 2014). Few scholars have recognized the importance of spatial and temporal attributes of resilience. For example, Frazier et al. (2013) built a set of place-specific indicators to estimate baseline resilience at a community level. However, these studies cannot capture spatio-temporal dynamics of resilience over the course of a disaster in terms of urban structure involving human activities. We need to study the dynamics from this new perspective to understand the holistic process of perturbation and recovery of both urban spatial structure and human movements.

To address the methodological challenges, we investigated bio-inspired approaches in the research area of ecology, which is the original study field of resilience. As resilience has emerged as a unifying concept across various disciplines including ecology and disaster management (Quinlan et al., 2015), approaches to quantifying resilience in ecology can provide diverse and fundamental insights in tracking urban resilience to disasters. We identified two effective tools in assessing and measuring resilience in this field: *network analysis* and *Fisher information*.

Network analysis has been proven to be a useful quantitative tool for exploring social-ecology resilience and tracking changes in vulnerability (Moore et al., 2014; Moore et al., 2015). It represents the complex ecology system as an aggregation of vertices and edges and makes it possible to be analyzed in standard mathematical approaches. Moreover, network analysis can also describe the connectivity among fragmented landscapes (Estrada and Bodin, 2008), characterize the spatially structured population in these landscapes (Bodin and Norberg, 2007), and disentangle the complexity within the spatio-temporal interactions between individuals and their environment (Jacoby and Freeman, 2016). These advantages show its potential in capturing the dynamic process of urban systems involving both human movements and spatial structure during natural disasters.

Fisher information (FI) was developed by Ronald Fisher (1922) as a measure of the amount of information of a parameter from observable data. It has been effectively used in measuring resilience in ecological systems by assessing changes in variables that charaterize the condition of the system (Eason and Cabezas, 2012; Eason et al., 2016; Karunanithi et al., 2008; Spanbauer et al., 2014). This information theory-based approach is beneficial in detecting both swift and subtle changes in system dynamics (Eason et al., 2016). Cities affected by disasters, involving fragmented spatial structure and perturbed human movements, are characterized by complexity. The complementary perspectives of networks and information processing are effective in describing complex systems. Therefore, we propose to combine the two tools to track the process of disaster resilience in cities.

Recent developments in information technology have provided an unprecedented amount of spatio-temporal data from diverse sources to study urban issues, such as human mobility patterns (Yan et al., 2014), human diffusion and city influence (Lenormand et al., 2015), land use and mobility (Lee and Holme, 2015), congested travels (Çolak et al., 2016), spreading of infectious disease (Brockmann et al., 2009), dynamic urban spatial structure (Louail et al., 2015; Noulas et al., 2015), and disaster resilience (Wang and Taylor, 2014, 2016). We also take advantage of these large-scale geolocations to bridge the data gaps in measuring disaster resilience. To begin, we used the human mobility network to describe the dynamic urban system. The movement network is reliant on the underlying urban spatial structures and social environment; it can help to reveal the impact of extreme events on human movement, usage of urban space, and spatial structure. The network is formed from aggregated geolocations at a daily basis in a disaster-affected city. Then we adopt FI in evaluating changes in network metrics over time. This helps clarify the dynamic process of resilience from a temporal aspect. Our study uniquely combined the two tools to evaluate both spatial and temporal aspects of urban resilience in the research field of disaster management.

METHODS: A BIO-INSPIRED APPROACH

Defining Urban Resilience to Disasters for Measurement

Resilience, though adopted in physics to describe the ability of something to return to its original shape after external shocks, gained its currency in the research area of ecology with a variety of definitions and measurements (Davoudi et al., 2012). A useful definition defines resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance" Holling (1973, p.14) also proposed two distinct concepts of resilience: engineering resilience and ecological resilience. The former denotes the ability of a system bouncing back to an *equilibrium* to respond to shocks and perturbations, while the latter underscores an adaption of a system to an *alternative* or multiple stable status instead of a single-state equilibrium (Davoudi et al., 2012; Holling, 1986;

Holling, 1996). Further, Carpenter et al. (2001) extended the definition of ecological resilience to social-ecological resilience to address the ability of system to stay in the domain of attraction, to self-organize, and to adapt.

Although definitions of resilience vary among diverse applications in different backgrounds, these three definitions provide a shared theoretical foundation to quantify resilience. It also worth noting that the particular context of resilience and a distinct way to define it will largely determine how it is quantified (Quinlan et al., 2015). Therefore, it is important for us to define resilience before the quantification. In our research context, urban systems involving mobility and spatial structure are complex and intrinsically dynamic. As it is difficult to define the optimal state of urban systems and to measure the exact impact caused by disasters, it is inappropriate to assume that the system can bounce back to an equilibrium state after external perturbations. Additionally, it is also difficult to quantify the capability of a system in self-organization and adaptation to measure social-ecological resilience with current data. Therefore, we defined urban resilience to disasters to align with *ecological resilience* to incorporate the inherently dynamic nature of urban systems.

Construction of Human Mobility Network from Geo-enabled Tweets

The raw data for building our human mobility network is comprised of geotagged Tweets collected from Twitter Streaming API (Wang and Taylor, 2015). We used geotagging as the only filter to collect real-time Tweets. As 1.24% of Tweets are geotagged (Pavalanathan and Eisenstein, 2015) and the streaming API can collect 1% of Tweets, our database is representative in terms of geo-enabled Tweets. The Twitter geotags are based on GPS Standard Positioning Service which offers a worst-case pseudo-range accuracy of 7.8 meters with 95 percent confidence, and the positional accuracy is affected by weather and device factors (Swier et al., 2015). The data process map can be found in Figure 1. We filtered geolocations into a disaster-affected city, and aggregated the filtered data into a human mobility network on a daily basis. This choice of temporal scale for forming a network can measure changes in network metrics and detect nuanced changes of the daily mobility network over time. The human mobility network formed in this study is a *weighted undirected* network, where nodes are distinct geographical locations, edges are displacements between two locations, and the number of displacements between the same pair of locations is the weight of the edge regardless of the direction.

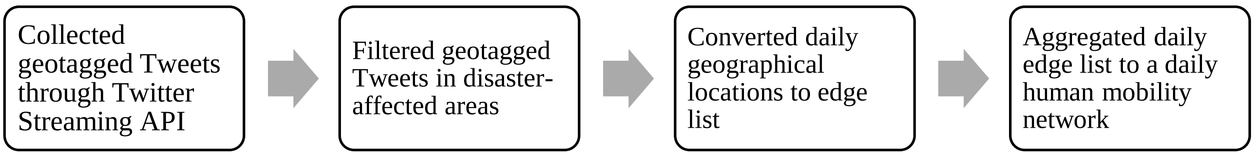

Figure 1. Process map of building Human Mobility Network

Network Metrics for Measuring Topological Dynamics

We considered a variety of network metrics to achieve a comprehensive description of a human mobility network (HMN) and the underlying urban spatial structure. One set of network metrics focus on *system-wide* properties, including number of vertices, number of edges, density, diameter, average path length, size of giant component, and global and local transitivity.

Specifically, *density* measures the proportion of displacements in HMN of all possible displacements in the same network. It can characterize the network-wide frequency of interactions between locations. *Diameter* of a mobility network is the maximal geodesic distance between any pair of locations, which reflects the ability of two locations to connect with each other. *Average path length* is the mean geodesic distance (ℓ) between two distinct locations in a network. *Giant component* describes all connected locations that a daily mobility network encompasses. *Transitivity* measures the probability that the adjacent locations of a trip are connected. We computed both *global transitivity* and *local average transitivity*. Global transitivity measures the fraction of triples that have their third edge filled in to complete the triangle. It is represented by the overall clustering coefficient $CI(g)$:

$$CI(g) = \frac{3 \times number\ of\ triangles\ in\ the\ network}{number\ of\ connected\ triples\ of\ nodes} \quad \text{(eqn. 1)}$$

where the connected triple refers to a node with edges to an unordered pair of nodes. While local transitivity is defined on an individual node basis:

$$CI_i(g) = \frac{number\ of\ triangles\ connected\ to\ location\ i}{number\ of\ triples\ centered\ at\ i} \quad \text{(eqn. 2)}$$

$$CI^{Avg}(g) = \frac{1}{n}\sum_i CI_i(g) \quad \text{(eqn. 3)}$$

Assortativity coefficient describes the level of homophily of a network (Newman, 2003). In HMN, this measurement quantifies the tendency of locations to be connected with other locations with similar connected displacements. We adopted the Pearson correlation coefficient with degree of adjacent vertices (Newman, 2002) (see eqn. 4 for the normalized correlation function).

$$r = \frac{1}{\sigma_q^2}\sum_{jk} jk\left(e_{jk} - q_j q_k\right) \quad \text{(eqn. 4)}$$

where q_k is the normalized distribution of remaining degree. σ_q^2 is the variance of q_k. e_{jk} is defined to be the joint probability distribution of the remaining degrees of the two vertices at either end of a randomly chosen edge. The coefficient lies between -1 to 1. Positive correlation indicates assortative mixing between locations of similar degree, while negative correlation is for disassortative mixing.

Fisher Information

We adopted FI to assess the process of perturbation and resilience in HMN. The form of FI in these studies are shown in equation eqn. 6 (Mayer et al., 2007).

$$FI = \int \frac{ds}{p(s)}[(dp(s))/ds]^2 \quad \text{(eqn. 5)}$$

Here, the urban mobility system is defined as a function of network variables which charaterize normal conditions and perturbed conditions due to extreme events. $p(s)$ refers to the probability of an observed network metric (s) of the urban system. The equation shows that FI is proportional to the change in the probability of observing an urban mobility state ($dp(s)$) versus the change in state (ds). In order to minimize the calculation errors, let $q^2(s) \equiv p(s)$,

$$FI = 4\int\left[\frac{dq}{ds}\right]^2 ds \quad \text{(eqn. 6)}$$

With discretization, $dq = q_i - q_{i+1}$ and $ds = s_i - s_{i+1}$. Additionally, the the state of the urban mobility system is denoted as ordinal number, $s_i - s_{i+1} = 1$. Therefore, the final equation for computing FI is:

$$FI = 4\int[q_i - q_{(i+1)}]^2 \quad \text{(eqn. 7)}$$

We interpreted the FI based on the *expanded Sustainable Regimes Hypothesis* (Karunanithi et al., 2008): (a) regimes are identified as periods with a stable and nonzero time-averaged FI; (b) a declining FI indicates a shift in a system with decreasing dynamic order; (c) an increasing FI signifies that the patterns are moving towards more stable patterns with increasing dynamic order; and (d) a regime shift is characterized by a steep drop in FI. Therefore, in this research, we assumed that the change of FI is consistent with dynamics of urban systems involving human movements and underlying spatial structures.

RESULTS

Overview of the Dataset

The metropolitan region of São Paulo, Brazil experienced a severe inland river flood during March 10 to 17, 2016 caused by extreme rainfall. São Paulo was selected as our studied area due to the high frequency of flooding in this area and its large urban population in South America (around 16 million inhabitants). This flood resulted in 24 casualties and 24 injured. The heavy rain began to fall on March 10, and ended the morning of March 11. 87.2 mm of rain was recorded in 24 hours in Mirante de Santana, north of São Paulo. We filtered collected geotagged Tweets into a *spatial bounding box* of the city of São Paulo with longitude from -47.3394 to -45.8134 and latitude from -24.1513 to -23.1762. The geographical box helps to include the largest size of flooding-affected area and population into our study. Five weeks of Tweets ranging from February 22 to March 27, 2016 are included in this study. This period consisted of two pre-flood and two post-flood weeks.

Pre-, During and Post-Flood Comparisons of Network-Wide Metrics

Over the five weeks, there are 2,449 daily average vertices (locations) and 2,194 daily average edges (displacements) included in a daily HMN. The dynamics of system-wide network metrics over weeks can be found in Figure 2. In this figure, each point represents a value of a network metric on a specific day. Each dashed line links the points to show the trend over time. Solid lines represent the Locally Weighted Scatterplot Smoothing of the scatter points. The two orange vertical lines define the duration of the flood event from March 10 to 17. The number of edges, number of vertices, and average degree (Figure 2(a-c)) follow a similar trend over time: all witness their peak values during the beginning four days of the flood event, and the values decrease with fluctuations after the peaks. The increased values at the beginning of the flood are likely to have been produced by the massive evacuation.

The value of edge density is very small (0.00068), which indicates that the daily aggregated mobility network is a sparse graph, and frequency of a displacement relative to another one is quite low in this network. The trend of this metric is quite steady and the impact of the flood is not obvious from visual inspection of the figure (Figure 2d).

Values of average path and network diameter also have similar trends over the weeks (Figure 2(e-f)). The mean geodesic distance between distinct pairs of locations achieves its highest value at 13.19 on March 10 when the flood began, then it drops to the lowest value of 5.83 on March 13. Similarly, on March 10, the diameter of the mobility network increases to 119. But four days later, HMN has the lowest diameter at 22. Both metrics keep increasing with fluctuations post-flood. These changes may have resulted from fragmentations in spatial structure and perturbations in the population’s movements. The flooding led to a fragmented landscape, which further increased the geodesic distance between different locations; besides, due to the heavy rains and accumulation of water, the fragmentation increased, and most connections have been affected. Therefore, geodesic distances between locations decreased remarkably after its peak value during the flood event.

The more fragmented landscape and perturbed mobility can also decrease the transitivity of HMN (Figure 2(g-h)). Under the normal circumstances pre-flood, the daily average value of global transitivity was 0.65. This means that there is a high probability of two locations connected with each other when they are in adjacent trajectory. However, this average value decreases to 0.31 during the flood, and it is even lower (0.27) post-flood. Local average transitivity behaves similarly with average values of 0.36 (pre-flood), 0.16 (in-flood), and 0.20 (post-flood), respectively.

Interestingly, the relative size of the giant component (daily average 13.85%) during the disaster is larger than the size during normal days (daily average 8.41%) (Figure 2j). The number of vertices contributing to the giant component is different under the two circumstances: 360.38 under perturbed circumstances versus 205.18 under normal circumstances (Figure 2i). This can be caused by the reduction of displacements between affected areas and an increase of travels from affected areas to unaffected areas in the city.

The assortativity coefficient is highly responsive to the flood compared to other system-wide metrics (Figure 2k). The coefficients are negative pre- and post-flood, indicating a disassortative mixing of HMN: locations are not connected to locations with similar degree. However, during the most severe flooding period (from March 11 to 14), the coefficient becomes positive but small, which suggests that HMN exhibits a low degree of assortative mixing patterns: locations become more connected to locations with similar degree. This transition can also result from fragmented landscape and the evacuation, which make less affected area more connected with each other by people’s movements, while more affected areas appear to have almost lost connections with other places.

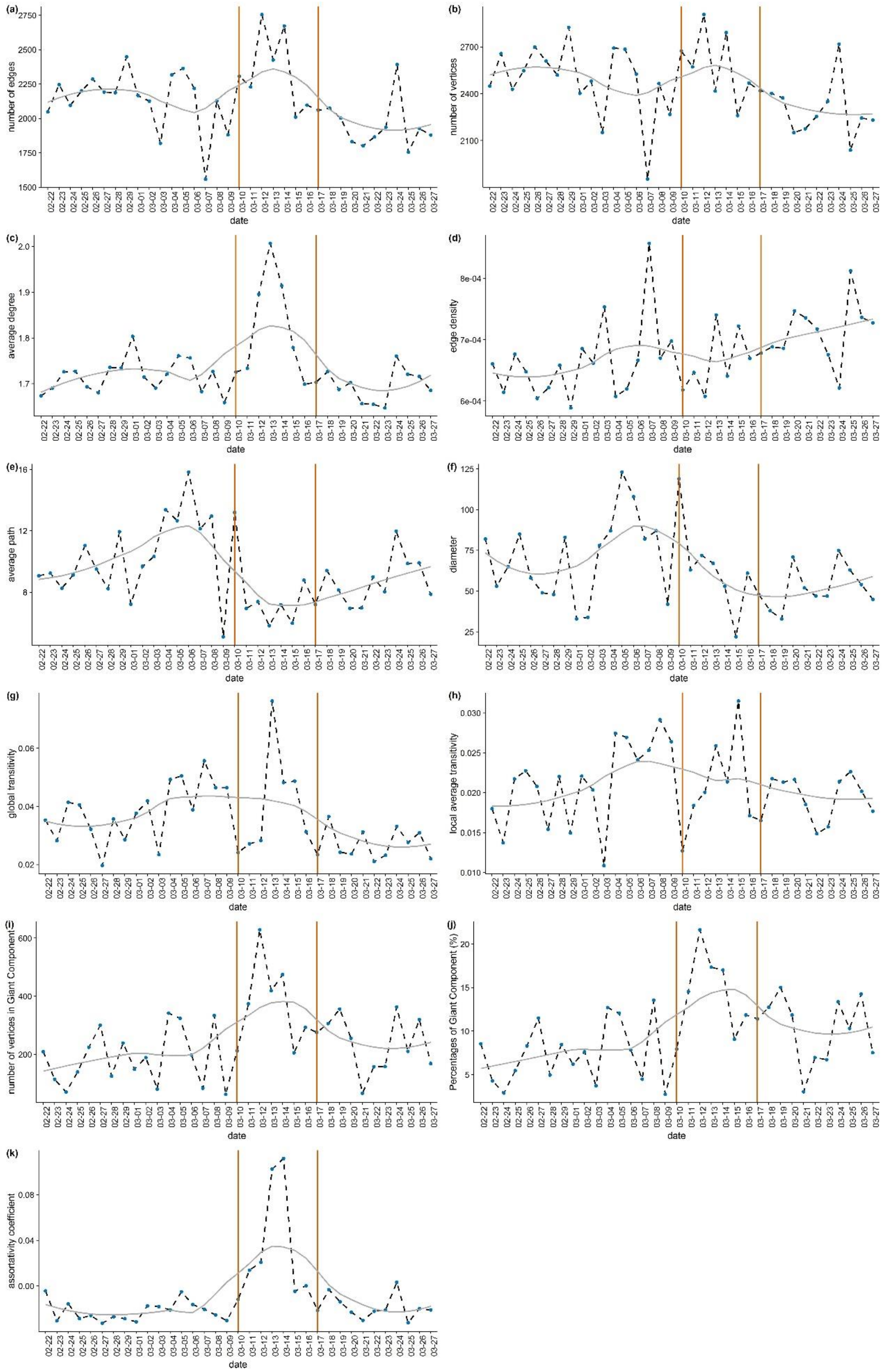

Figure 2. Dynamics of network-wide metrics over five weeks.

To further examine if the flood has statistically impacted the network-wide metrics, we conducted *adjacent-categories logistic regression* analysis to investigate the relationship between three states (i.e. pre-, during- and post-disaster) and each distinct network metric. Adjacent category regressions are a specific form of generalized logistic regression for multinomial outcomes (O'Connell, 2006). This approach compares response outcomes of adjacent categories. Before the regression analysis, we performed the *runs test* (Bradley, 1968) for detecting the randomness in values of each network metric (Table 2). *p-values* of all data sets are larger than 0.05, which indicates that values of each network metric are random, and adjacent-categories logistic regression is appropriate to be used. We then set the three states as ordinal response variables (specifically, 0 for the pre-flood state, 1 for the state during the flood, 2 for the post-flood state), and set a network metric as an explanatory variable in each logit model. The outcomes and *p-values* can be found in Table 2.

For the comparisons between pre- and during-flood states, the significance tests of the logistic regression reveal that assortativity coefficient, average path, and size of giant component are three metrics that have been significantly impacted by the flood event ($p < 0.05$). In comparison, number of edges, vertices, average degree, and global transitivity only exhibit statistically significant differences post-flood. They are relatively resistant to the flood at the beginning. Notably, assortativity coefficient is the only metric that responds to each state change, but metrics such as edge density, diameter, and local transitivity are stable over the course of three adjacent periods.

Table 2. Randomness of values of network metrics and outcomes of adjacent-categories logistic regression and significance tests

	Standardized Runs Statistic	*p-value*	pre vs. during	*p-value*	during vs. post	*p-value*
number of edges	-1.884	0.05957	-0.003744	0.08848	0.008310	0.00573 **
number of vertices	0.34832	0.7276	-0.00192	0.3817	0.006196	0.0243 *
average degree	-1.1971	0.2313	-18.230	0.0514	35.072	0.0189 *
assortativity coefficient	- 0.85368	0.3933	-150.5485	0.00836 **	106.5233	0.04288 *
edge density	-0.85368	0.3933	-488.201	0.955	-14705.559	0.118
average path	-1.0449	0.296	0.5772	0.0305 *	-0.2863	0.2894
diameter	-1.5405	0.1234	0.01345	0.481	0.02629	0.282
global transitivity	-0.85368	0.3933	-0.7187	0.9836	137.7141	0.0337 *
local transitivity	-1.1971	0.2313	39.60258	0.670	41.15769	0.692
giant component (#)	-0.5103	0.6099	-0.0149	0.00875 **	0.00977	0.07024
giant componnet (%)	-2.0899	0.03663	-0.4375	0.0051 **	0.234	0.09743

Significance: ‘***’ p<0.001; ‘**’ p<0.01; ‘*’ p<0.05.

Analysis of Resilience Based on Fisher Information (FI) of Network-Wide Metrics

We further computed the FI of all the network-wide metrics using a set of Python codes (Ahmad *et al.*, 2015). Each day was taken as a time step. Given the 35 days of data, eight time steps were set as a window size (Eason and Cabezas, 2012) to ensure that one point in the window does not improperly affect the general computation. The window increment was one time step. Herein, FI was integrated over an eight-day window that is moved forward in one-day increments. Values of a network metric in each time window were binned into discrete states. The probability density was then computed in each time window, and provided the basis for calculating FI. Figures 3 (a-k) are plots of FI for the 11 network-wide metrics over 28 days in the study. Metric values of the beginning eight days were used to calculate the initial value of FI. The orange bars highlight the flooding period and vertical grey lines define weeks.

According to the *expanded Sustainable Regimes Hypothesis* (Karunanithi et al., 2008), changes in values of FI can imply changes in regimes for the dynamic urban system. Except for FI of diameter, declining FI trends during the flooding period are found for almost all network metrics, indicating that the dynamic order decreases and the system becomes less stable. For network metrics—i.e. edge number (Figure 3a), vertice number (Figure 3b), average path (Figure 3f), and global transitivity (Figure 3h) —a local FI minimum occurs in the middle of the flooding period; for network metrics—i.e. average degree (Figure 3c), assortativity coefficient (Figure 3d), local transitivity (Figure 3i), and size of Giant Component (Figure 3k-j) —a local FI minimum occurs at the end of the flooding period. For all of these network metrics, their FI gradually increases after the lowest value, signalling the system gains dynamic order and becomes more stable. Post-flood values of FI may be lower or higher than the pre-flood values, which indicates an alternative stable status rather than an equal stable status. For the overall system, results of the FI assessment of network-wide metrics indicate that the examined urban system exhibited no "regime shift" due to the flooding because there is no shifted FI value over the studied period. Additionally, the system exhibits resilience over the studied period: it lost dynamic order and became less stable during the flood, but gradually bounced back to an alternative stable status after the perturbation.

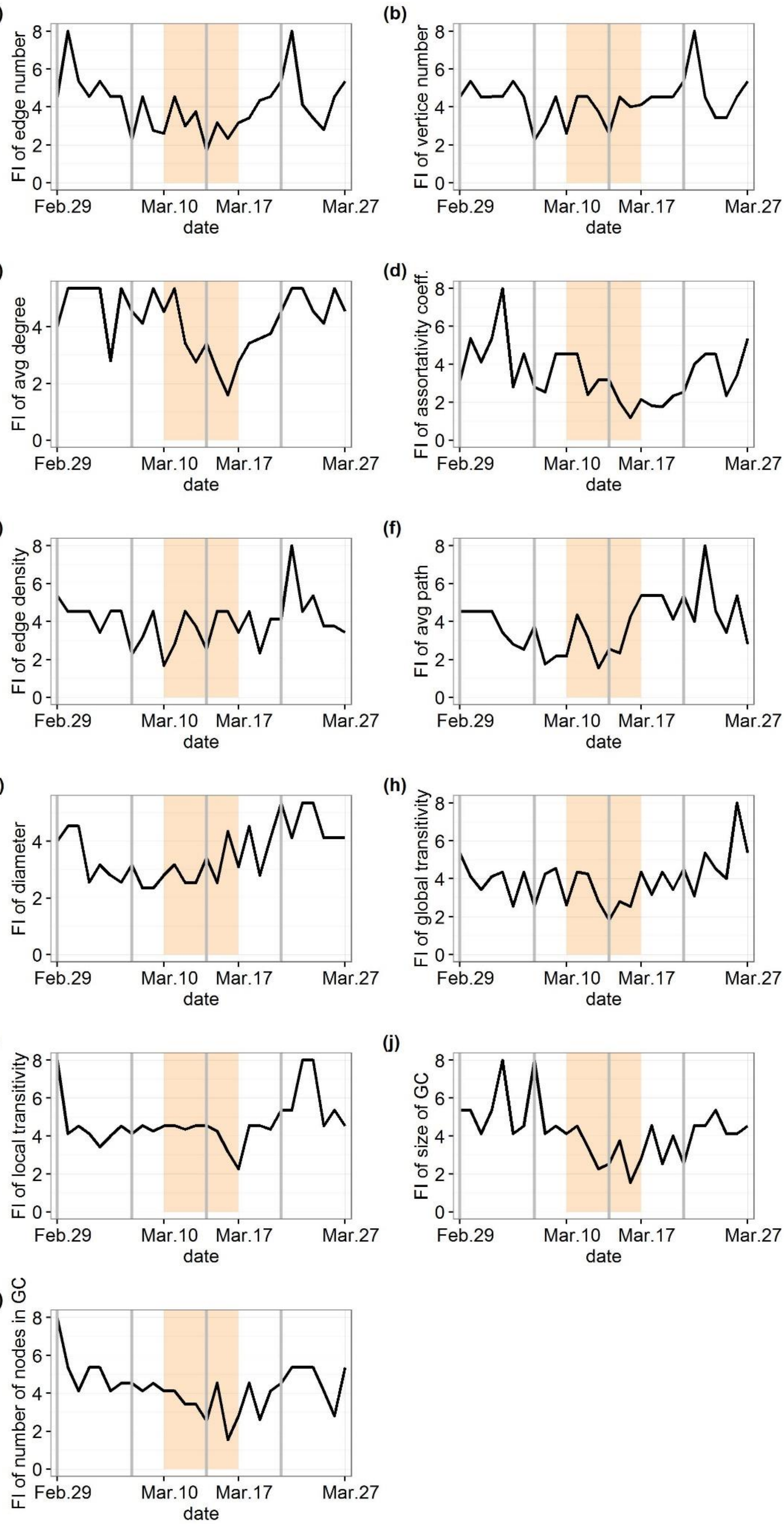

Figure 3. Trend of FI of network-wide metrics over time.

DISCUSSION

Previous work on measuring disaster resilience tends to be conceptual rather than quantitative (Cimellaro et al., 2010; Zobel, 2011; Zobel and Khansa, 2014). These resilience assessment frameworks have been applied to management systems and for building capacity in communities. Despite the fact that different dimensions of resilience have been addressed in different contexts and systems (Cutter et al., 2014; Cutter and Finch, 2008; Frazier et al., 2013; Lam et al., 2015), it is still difficult to quantify resilience in ways that are flexible and appropriate across a range of urban systems. Besides, although resilience has been identified as a dynamic process, few current assessments include the dynamics of how urban systems respond to disasters from both spatial and temporal aspects. Simultaneously, in spite of the shared theoretical foundations of resilience across different scientific disciplines, little cross-fertilization progress has been made, save for a handful of examples (Barrett and Constas, 2014; Quinlan et al., 2015). Our studies were inspired by definitions and approaches in measuring resilience in the pioneering field of resilience research: ecology. We applied network analysis in characterizing an urban system and used FI to detect dynamics in the resilience process.

Our constructed human mobility network can describe the dynamics of urban mobility and the underlying spatial structure. It is more representative of a general mobility network compared with networks formed from a single type of transportation mode. It is worth mentioning that our study is different from previous studies on modeling/simulating network resilience of infrastructure networks (e.g. freight transportation network, metro network, railway network, etc. (Miller-Hooks et al., 2012; Bhatia et al., 2015; Chopra et al., 2016; Gao et al., 2015; Wang, 2015)). Our research is focused on empirical data and used network metrics to describe the system. Our results show that most network metrics can capture the change of the urban mobility network and its underlying spatial structure. The *adjacent-categories logistic regression* further examined the statistically significant impacts of the flood. For distinct network metrics, the impact can be either at the beginning or at the end of the event. However, some network-wide metrics are less responsive to the perturbation of the flood. This indicates the intrinsic resilience of urban systems.

One limitation of our research is the sample size. Clearly, 2,449 daily average vertices in HMN are not enough to make generalizations about the network of all locations in a megacity. However, from the results, it can show the impact caused by the flood. With more geo-temporal data with higher resolution, a directed and weighted mobility network can be built to explore these concepts further. Additionally, a smaller time window (e.g. half day, hourly) and higher accuracy of geolocations can be used to form a network to achieve a more nuanced spatio-temporal analysis. Our proposed approach has only been applied in one type of natural disaster. With increasing availability of geographical and disaster data, this bio-inspired method can also be used in assessing urban resilience to other types of disasters such as hurricanes and earthquakes. And we can also compare resilience of the same type of disaster among distinct cities. In this way, we can explore the baseline of resilience and impact factors on the resilience, such as the scale of the study area, magnitude of disasters, etc. In terms of the research assumption, we used *ecological resilience* as the basis for quantification. With deeper understanding of urban systems, we may also assume urban resilience as socio-ecological resilience to explore and measure the capability of adaption and self-organization of systems.

CONCLUSIONS

Defining and measuring resilience is an important step to address challenges caused by natural disasters. It is of critical importance to help complex urban systems quickly recover and adapt when extreme events occur. Our study contributes to knowledge in the following ways. First, it adds to the paucity of empirical literature on measuring urban resilience to disasters. We provide a quantitative framework for describing and tracking the dynamic process of resilience in terms of human mobility and underlying spatial structure at both spatial and temporal scales. Second, our method is repeatable with large-scale crowed sourced spatio-temporal data from diverse resources such as mobile phone records, social media, GPS devices, etc. Upon further validation, it can be utilized at different scales (e.g. city, area, country and larger scales), and provide convenience for spatial comparisons. Third, it paves the way for further research on quantifying resilience of a larger complex system involving urban spatial structure and human movements; moreover, this study devotes effort in measuring resilience as a unifying concept across disciplines through a bio-inspired endeavor. In practice, combining with more detailed meteorological and geographical data, our framework can help disaster managers to trace and evaluate the process of perturbation and recovery more easily. This can further facilitate effective strategic decision making regarding when and where to arrange resources during and after disasters.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1142379 and the Virginia Tech BioBuild Interdisciplinary Graduate Education Program (IGEP). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the BioBuild program.

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A Review on the Influence of Social Attachment on Human Mobility During Crises

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ABSTRACT

Human behaviour during crisis evacuations is social in nature. In particular, social attachment theory posits that proximity of familiar people, places, objects, etc. promotes calm and a feeling of safety, while their absence triggers panic or flight. In closely bonded groups such as families, members seek each other and evacuate as one. This makes attachment bonds necessary in the development of realistic models of mobility during crises. In this paper, we present a review of evacuation behaviour, theories on social attachment, crises mobility, and agent-based models. We found that social attachment influences mobility in the different stages of evacuation (pre, during and post). Based on these findings, we intend to develop a multi-agent model of mobility during seismic crises, using the belief, desire and intention (BDI) agent architecture.

Keywords

Multi agent modelling, social attachment, affiliation, human behaviour, mobility

INTRODUCTION

The *mobility* of individuals during evacuations is of paramount concern during disasters. Quick thinking and decision making to move immediately towards a safe area saves individuals from danger. Mobility is influenced by: physical factors such as age, gender, body type; human factors such as emotions (calmness, level of fear, contagion) and cognitive aspects (knowledge and experience); environmental factors (presence of obstacles, obstruction, facilities promoting mobility); and social interactions and attachment, such as to family members or to specific places.

This paper focuses on the influence of *social attachment* and how it affects mobility in crisis situations. By social attachment we mean the strong and weak bonds produced by relationships and interactions of individuals with others, namely family members, close kin, friends, colleagues, authority figures (leaders), and even strangers. We also include the influence and affiliation to familiar objects, places and tasks (such as, personal belongings, the home and continuing to work, respectively) which are closely associated with these bond-related social interactions. The goal of our work is eventually to develop of a multi-agent model simulating human behaviour during crises situations, integrating social attachment. The simulator will be used to investigate the effects of attachment bonds on the mobility of individuals and emergent groups during evacuations in crisis scenarios. In particular it will look at the nuances where attachment is beneficial or detrimental in the evacuation of large populations during crises.

A computational *agent* is a discrete entity defined in terms of its attributes and behaviours. Wooldridge and Jennings describe agents to be autonomous, operating without direct human intervention, having social ability (i.e. interacts with other agents), able to perceive and respond to their environment, and exhibiting goal directed behaviour (Wooldridge and Jennings, 1995). Gilbert and Troitzsch adds that agents can be constructed to simulate some simplified aspects of human intentions which can include beliefs, desires, motives and emotions (Gilbert and Troitzsch, 2005). Multi-agent systems (MAS) allow heterogeneous agents to cooperate according to complex modes of interaction (Ferber, 2007). MAS have been used to investigate several phenomena and have proven to be a powerful tool for modelling in the social sciences and other related fields (Kravari and Bassiliades, 2015). Among the MAS architectures, a belief, desire, and intention (BDI) approach is ideal for modelling people (Adam and Gaudou, 2016). From Adam and Gaudou, BDI attempts to capture the common understanding of how humans reason with: *beliefs* which represent knowledge of the environment and the agent's self or internal state, *desires* or the goals the individual decides to achieve, and the *intentions* which describe a set or sequence of steps needed to achieve the determined goals (Adam and Gaudou, 2016). Still from the same authors, BDI architecture allows an agent to *err*, by having subjective representations of the environment in terms of beliefs that can be incomplete, flawed or different from other agents, can communicate and reason with other agents, have the ability to explain behaviours, exhibit emotion, able to internalize norms, and capable of making independent decisions.

Agent based modelling (ABM) involves the representation of human behaviour in a geographic space, participating in social interactions within a computational environment. In our model agents represent humans and are autonomous and are endowed with mobility through human physical, cognitive, emotional and social attributes in the simulated space. Non-human objects such as pathways (doors, hallways, alleys and roads) and obstacles (walls, barriers, debris, natural features like rivers), define spatial geometry, delimit human agent behaviour, and can either facilitate or restrict movement and social interaction. Agent interactions can produce groups, or large crowds with characteristic behaviours emerging from particular situations such as evacuations during crises.

The structure of this paper is as follows. The next section presents the state of the art in behaviour modelling for crisis, and is further divided into subsections: trends in human behavioural modelling during crises, reactions to crisis, the stages of evacuation, mobility, and human behaviours observed during evacuations. The next section then presents the relevant social theories on attachment that explains these behaviours. Agent based models of social attachment are discussed in a further section. The paper closes with a discussion, conclusion and some ideas for future work.

STATE OF THE ART IN BEHAVIOUR MODELLING FOR CRISES

Trends in Behaviour Modelling for Crises

Human behaviours in evacuations are social in nature (B. Aguirre, 1983; Chu, Pan, et al., 2011) and understanding social and group processes during evacuations such as the activation of existing bonds during threat, formation of new ties leading to the creation of groups, and interactions between individuals and groups, can lead to the development of more realistic behavioural models.

A recent trend in crowd modelling is the development of intelligent agents incorporating social and psychological factors (Zhou et al., 2010). A fundamental understanding of these factors in the context of pedestrian evacuation behaviours is needed to develop more realistic computer simulations (E. Galea, 2003; Chu, Pan, et al., 2011). Current egress simulation tools however lack human and social behaviours (Chu, Pan, et al., 2011). Social group process modelling and evaluation of its impacts to human behaviour is also very weak (Zhou et al., 2010; Santos et al., 2004). Johnson et al. shares this view and stresses the need for the better psychological understanding of group behaviour on decision making (P. F. Johnson et al., 2011). Agents should have the capability of identifying themselves with a group and able to resist separation, as enhancements to current models (Samuelson, 2011). Peacock et al. also recommend that future research should investigate how interactions between people within groups alter individual speeds (R. Peacock et al., 2011). Considering these behaviours in the development of evacuation plans by cities and municipalities can greatly enhance plan effectiveness (Urata and Hato, 2012).

Reactions to Crisis

Disasters can be characterized by the time of occurrence and the availability of warning. Sudden onset events occur without warning and last a few seconds, such as earthquakes, terrorist attacks, industrial accidents, landslides, etc. (Norton et al., 2013). People are generally caught unaware and unprepared in these events. Longer duration events such as fire, tsunami, typhoons, floods can often be anticipated and warning is usually available, allowing people to prepare or evacuate.

Emotional reactions to crises are triggered by environmental or social cues and shape behaviour. These include fear, confusion, anger, bewilderment, etc. which either starts, hastens, stalls or stops evacuations. In a group, emotional cues are quickly detected by members and affect the behaviour of the group (Papelis et al., 2011). Without appropriate cues and knowledge, people may wait and see or evacuate improperly (P. F. Johnson et al., 2011). The decision to evacuate can be facilitated by: (1) observations of the threat, (2) instructions to evacuate, (3) fear, (4) evacuation of friends and co-workers, and (5) previous evacuation experience (Averill et al., 2005). People tend to adjust their behaviour with respect to the severity of the threat, and generally do not evacuate at the same time (Sorensen, 1991).

Evacuation

Evacuation is the temporary mass physical movement of people that collectively emerge from coping with threats, damages or disruptions (B. Aguirre, 1983). Success in evacuating people to safety is characterized by the time needed to evacuate and the time available to reach safe areas (Averill et al., 2005; Kuligowski and Hoskings, 2010). Delayed evacuation has been the cause of many deaths during disasters such as in the September 11, 2001 terrorist attack on the World Trade Center (WTC) in the United States (Averill et al., 2005); and the 2011 Great East Japan earthquake and tsunami (S. Fraser et al., 2012). Stages of evacuation includes pre-evacuation, evacuation and post-evacuation. Most of the delays are from behaviours during the pre-evacuation stage such as seeking information, group formation, inaction due to freezing, or continuation of current activities due to non-recognition of the threat (Kuligowski and Hoskings, 2010). Helping or assisting mobility impaired individuals occurs during the pre-evacuation and egress phases. Although this increases the chances of survival of the mobility impaired, it delays the effective evacuation of the altruistic individuals and their group (Averill et al., 2005; R. Peacock et al., 2011; Daamen and Hoogendorn, 2011).

Gwynne notes that data on evacuations are needed in the development of plans, and are critical for the responsible engineering design of structures, but these are difficult to find, understand and apply (Gwynne, 2011). Gwynne traces this difficulty back to several factors: the relative immaturity of the domain, comparatively recent realisation of the importance of human behaviour in egress calculations, technical factors with respect to data collection methods, privacy and commercial sensitivity of results, and other procedural and political factors.

Mobility during evacuation

Most evacuation research is based on the mobility of normally able adults (Larusdottir and Dederichs, 2011). Therefore the developed plans are unrealistic, as they do not include the mobility impaired which comprise substantial portions of the population. Ten to twenty percent of the population of European countries for example have mobility impairments (Bengston et al., 2011). Globally, the ageing population (aged sixty years or over) is growing faster than any age group particularly in advanced countries and most live in urban areas (United Nations, 2015). Mobilities of elderly people diminish over time, impaired by decreased eyesight, hearing and wayfinding abilities (Bengston et al., 2011). Walking speed also decreases with age (Bohannon, 1997). Stairs provide a particular difficulty for disabled people during evacuations, as well as opening heavy doors (Bengston et al., 2011). Children need assistance during evacuations in locations such as from the home and in schools. Larusdottir and Dederichs found that evacuation characteristics of children, such as travel speeds in horizontal planes and down spiral stairs, and the flow through doors, is very different from those applied in simulations from literature (Larusdottir and Dederichs, 2011). Medical conditions such as arthritis, cerebral palsy or pulmonary, cardiac or other illnesses also limits mobility (Averill et al., 2005; Manley, 2012). Evacuating people with reduced mobility especially from multi-storey buildings is a difficult task (Adams and E. R. Galea, 2011). For tall buildings, most evacuations occur in staircases with longer evacuation routes, amplifying the possibility of failure due to fatigue and decline of physical strength of evacuees (Choi et al., 2011).

Altruism and helping behaviours are common during crises (Cocking et al., 2007). Groups with mobility impaired members, particularly the disabled, tend to remain together at the speed of the slowest member, and this clumping effect constricts pathways effectively slowing the evacuation speeds of other individuals and groups in the same location (Samuelson, 2011).

Evacuation speeds (meters/second) of individuals with different mobilities and scenarios of locomotion have been collected from several studies and are presented in Table 1. The use of a range of speeds rather than single values as attributes of agents in models can produce more realistic simulation results (R. Peacock et al., 2011). Changes in speed at different intervals during evacuations can be due to different interactions with other evacuees facilitated by differences in characteristics and physical abilities (Choi et al., 2011). Individuals carrying objects or persons during evacuations are generally slower (R. Peacock et al., 2011). In some cases evacuations can be triggered. For example, seeing a child in trouble could invoke a rapid response in another person.

The force of the disaster can also affect mobility. During an intensity six earthquake for example, many will find it difficult to remain standing (S. Fraser et al., 2012; H. O. Wood and Neumann, 1931; Grunthal, 1998), forcing

Table 1. Evacuation Speeds

Source	Mode	Category	Individual (m/sec)	Group (m/sec)
(Kady and Davis, 2009)	Crawl	All body types	0.65 - 0.90	
(Adams and E. R. Galea, 2011; Kady and Davis, 2009; S. A. Fraser et al., 2014)	Walk	Children Adult Elderly	0.56 - 0.84 0.91 - 1.73 0.70 - 1.11	- 0.88 0.75
(Adams and E. R. Galea, 2011; N. J. Wood and Schmidtlein, 2012)	Run	Children Adult Elderly	1.14 - 2.23 1.78 - 3.83 -	
(Shi et al., 2009; Boyce et al., 1999)	Disabled	All types	0.10 - 1.77	0.21 - 1.98
(Adams and E. R. Galea, 2011)	Rescue device	All types		0.55 - 1.5
(Larusdottir and Dederichs, 2011; R. Peacock et al., 2011; S. A. Fraser et al., 2014)	Stairs	Children Adult Elderly	0.25 - 1.4 0.056-1.7 0.21	

people to crawl instead of walking or running to exits. Debris can block pathways or completely trap individuals. Poor visibility from dust, smoke or absence of lighting/power can hinder mobility during evacuations. Congested pathways and exits due to crowding can also slow down egress (Choi et al., 2011).

Evacuation Behaviour

Averill et al.'s study of the September 11, 2001 terrorist attack on the WTC in the United States revealed several behaviours during the crisis (Averill et al., 2005). This well studied event can provide insights into earthquake, fire, and terrorist bombing incident-related behaviours as: (1) most of the building occupants felt the shaking of the building first, and the eventual collapse of the structures, similar to a very strong earthquake; (2) spread of fire and smoke in several floors; and (3) terrorist attack when the cause of the explosions became known (Averill et al., 2005). Pre-evacuation behaviours include: (1) talking to others; (2) gathering personal items; (3) helping other people; (4) searching for others; (5) talking on the phone; (6) moving between floors. Occupants sought information ('milling' behaviour) prior to evacuation from face-to-face conversations, telephone, television, or radio, e-mail or hand-held devices, and from building announcements.

Selfish behaviours are rare during disasters and what has been observed is the prevalence of altruism, with people helping others (Cocking et al., 2007). In the WTC event (Averill et al., 2005), many survivors reported giving and receiving help during their evacuation. Occupants helped others even when aware of the heightened risk, before proceeding with their own evacuation. Twenty percent (20%) reported being helped by someone and thirty percent (30%) helped others. Individuals helped others with mobility impairments induced by injury, disability, heath conditions, pregnancy and age. Sources of help included co-workers; manager/supervisor; floor warden, police officer/fire fighter and strangers. However, it should also be noted that some who helped other people perished due to delayed evacuation times and were caught in the structural collapse of the WTC Towers 1 and 2.

Helping behaviour between strangers was also reported by Drury et al. during the evacuation of survivors from the London bombing of 2005 (Drury et al., 2009). They note that instead of personal selfishness and competition, survivors helped each other despite being among strangers. Interestingly panic was not reported by the interviewed survivors.

Cooperative behaviours were modelled by Urata and Hato (Urata and Hato, 2012) to understand the complications produced by the delayed evacuation of residents during the 2011 Great East Japan Earthquake and Tsunami. Cooperative behaviour included: information exchange about dangers and safe places, and mutual assistance to aid individuals with low mobility.

Group interaction was observed by D'Orazio et al. from the analysis of earthquake evacuation video data (D'Orazio, Spalazzi, et al., 2014). The observed groups: exchanged information, moved closer together, and evacuated away from danger. Individuals either followed other individuals (leader-follower behaviour) or formed groups (herding or flocking behaviour). Their work was conducted to address the lack of post-earthquake human behaviour data and studies especially during the pre-evacuation phase. This was also an attempt by the authors to relate human behaviours to the assessment of seismic risk at the urban scale. Benefits of this include providing appropriate policy measures for disaster risk reduction (Bernardini et al., 2016). The authors developed an agent based evacuation model by modifying Helbing's Social Force Model from the derived pedestrian behaviours.

Leader-follower behaviour was also implemented by Beck et al. in modelling crisis mobility of pedestrians during earthquakes in Lebanon and Argentina (Beck et al., 2014). Agents are able to perceive other agents, move and follow leaders.

Flight behaviour is one of the strongest features of mass behaviours in Italian earthquakes (Alexander, 1990). This anxious behaviour can traced back to previous hazard experiences such as the eruptions of Mount Vesuvius, existence of other hazards and the poor structural integrity of old buildings. During tremors, residents generally seek out family members, run outdoors and regroup with other members. Those away from home, return to check on family members and resulting damage to their dwellings.

Close family relationships is also highlighted in Jon et al.'s study of behaviours during the Christchurch, New Zealand and Hitachi, and Japan earthquakes (Jon et al., 2016). Notable behaviours included: (1) contacting family members, (2) protecting children, (3) going home, (4) going to the home of a relative, or friend. This agrees with the findings of Mikami and Ikeda who found that people during disasters tend to get together with family members; and try to ensure the safety of all members and evacuate together (Mikami and Ikeda, 1985). These behaviours were also reported by survivors in the 2011 Great East Japan earthquake and tsunami. However many people died unnecessarily due to delayed evacuation or non-evacuation from adressing social or parental responsibilities (S. Fraser et al., 2012). Heath et. al., in the study of household evacuation during the California 1997 floods, found that households with children successfully evacuate, more than those without (Heath et al., 2001). This can be explained by the need of parents to protect their children. The authors also found that some households treat pets as family members and owners prefer to stay with pets or due to the logistical difficulties of capturing or transporting pets, owners stay at home.

The aforementioned examples demonstrate the social nature of human behaviour during crisis evacuations. These are governed by social bonds that are either strong and fixed such as within family members or weak and dynamic with friends or colleagues, or strangers. These ties strongly influence behaviour when individuals evacuate as families, groups of strangers, or large crowds.

The novelty of the work is the incorporation of human bonds/relationships and social groups in a multi agent based model for crisis evacuations for a large city using real geographic data. This work advances previous works by considering: (1) different documented evacuation behaviours (grounded on social theories), (2) a large heterogeneous population of agents with different attachment bonds, demographic characteristics and mobilities, and (3) interactions within a large geographic area. If successful the work could have significant impact in validating and improving crisis management plans.

A summary of the behaviours during disasters is shown in Table 2. We categorized the behaviour into the three evacuation stages and give specific actions.

SOCIAL ATTACHMENT AND RELATED THEORIES

We define social attachment in the context of bonds between individuals. This is developed from childhood within the family and modified towards adulthood from social interactions. These attachment bonds regulate behaviour whenever social interactions occur. Evacuations, as social events, are either facilitated or hampered by these social ties. Attachment bonds can affect crisis behaviour by regulating fear (dampening or amplifying panic); create groups and crowds; promote altruism between strangers and among group members; and create orderly behaviour during egress.

The effects of social social attachment on evacuation behaviour can be explained by the following theories. These theories have been selected as being those that most accurately explain evacuation behaviours. (1) Normative Theory is presented as the default behaviour where the assumption is that behaviours in daily life are still the norm during disasters; (2) Emergent Norm Theory modifies Normative Theory and explains abnormal behaviours during crises events; (3) Panic Theory is the common explanation used to explain seemingly chaotic and unexplained behaviour; (4) Attachment Theory explains the calming effects that are provided by attachment figures enabling individuals to control fear thus avoiding panic; (5) Social Attachment Theory defines attachment specifically for disaster events, emphasizes the role of bonds with familiars, and proximity seeking behaviours; (6) Social Baseline

Table 2. Evacuation Behaviour

Stage	Behaviour	Action	Source
Pre-evacuation	Seeking information	Milling, talking to others (by phone, face to face)	(Averill et al., 2005; Bernardini et al., 2016; D'Orazio, Quagliarini, et al., 2014; Kuligowski and Hoskings, 2010)
	Seeking family members/other people	Calling, searching	(Jon et al., 2016; Mikami and Ikeda, 1985; S. Fraser et al., 2012; Alexander, 1990)
	Manage objects	Get belongings, shut down computers, turn off power/gas	(Averill et al., 2005)
	Freeze	Stay in place	(Prati et al., 2012; Lindell et al., 2016)
	Maintain activity	Continue working, driving	(Averill et al., 2005)
	Seek protection	Drop-cover-and hold on	(M. M. Wood and Glik, 2013; D'Orazio, Spalazzi, et al., 2014)
	Helping	Protect others, assist mobility impaired (children, pregnant women, elderly, disabled, injured)	(Urata and Hato, 2012; Kuligowski and Hoskings, 2010)
Evacuation	Flight	Move (walk, run, crawl), use stairs, elevator, head home, go to nearest exit or safe area	(S. A. Fraser et al., 2014; Kady and Davis, 2009; Kuligowski, R. D. Peacock, et al., 2015; Alexander, 1990; Averill et al., 2005; D'Orazio, Quagliarini, et al., 2014)
	Following	Follow leader, herding, flocking	(Beck et al., 2014; D'Orazio, Quagliarini, et al., 2014)
	Helping others	Assist mobility impaired	(Cocking et al., 2007; Averill et al., 2005)
Post Evacuation	Regrouping	Regrouping with family members, friends, colleagues	(Prati et al., 2012)
	Helping/Rescue	Returning to danger area to rescue family member, friend, colleague	(S. Fraser et al., 2012; D'Orazio, Quagliarini, et al., 2014)
	Recover objects	Return home to get supplies	(Prati et al., 2012)

theory explains the tendency of individuals to maintain close proximity and the role of risk assignment; (7) Social Defence Theory defines ideal types of members in a group to achieve optimal survival; (8) Self Categorisation Theory explains the process where individuals transition to become members of groups; Finally (9) Social Identity Theory describes the role of shared identities and bond formation between strangers, effectively addressing the limitations of Social Attachment Theory.

Other related theories such as social comparison theory (Festinger, 1954), decision making theory (Chu, Pan, et al., 2011; Mintz, 1951), contagion (Wijermans, 2011), social proof (Cialdini, 2006), and proxemics (Hall, 1990) will not be discussed as these do not directly deal with social bonds.

Normative Theory states that everyday social rules and roles that govern daily life can also be observed in emergency situations (Chu, Pan, et al., 2011). Examples of these are: respecting and helping elders, caring and prioritizing children, aiding the disabled, following traffic rules, following authority figures, and maintaining social organisation. Normative theory therefore assumes the predictability of human behaviour during disasters. Expected proper behaviour during disasters are prescribed in manuals and evacuation plans and practised in drills. Social norms are likely to be followed during slow evolving disasters where there is longer time available to evacuate (Frey et al., 2011).

Illogical behaviours however are observed during disasters and can be due to the differences in how individuals handle the stresses imposed by crises. Under extreme stress, cognitive reasoning is affected. For example, individuals may follow familiar but not optimal evacuation pathways or may forget about learned routes and exits from drills (Rai and Wong, 2009). Stresses during crisis also make individuals prone to cognitive biases, distorting judgement and decision making leading to undesireable consequences (Comes, 2016; D. Johnson and Levin, 2009; Murata et al., 2015).

Emergent Norm Theory posits that crisis destroys traditional normative guidelines defining appropriate behaviour, and individuals, because of the urgency of the situation. People are forced to interact and create new meaning or norms to guide behaviour (B. E. Aguirre et al., 1998). Also, once a dominant norm is defined, group members with differing opinions keep quiet for fear of group censure. Aguirre et al. (B. E. Aguirre et al., 1998) adds that enduring social relationships determine social interactions associated with the emergence of a dominant norm resulting from an instance of collective behaviour such as risk taking, use of resources and cooperation.

Panic Theory - Panic refers to inappropriate or excessive fear and/or flight (Mawson, 2005). It is where instinct, overwhelms socialisation, dissolves collective bonds, and survival becomes the objective of the individual resulting in competitive behaviours within the crowd (Strauss, 1944; Drury et al., 2008). Panic can be seen on two levels: (1) individual panic as disorganisation due to fear; and (2) mass panic as disorderly flight leading to disastrous results for crowds (Ma et al., 2011). Crowd stampedes for example are caused by panic leading to fatalities where people are crushed or trampled by the crowd (Helbing, Farkas, et al., 2000).

Mawson's review of the previous literature on panic yielded the following: (1) the following behaviours can be described as panic: manic or hyperactive behaviour, flight, aggression, desperate attacks on people, emotional explosion, agitation and motor restlessness, and immobility of freezing, (2) individuals experiencing panic are susceptible to social influence, such as being infected with fear, or mimicking the behaviour of others (looking when others run, escaping through the same exits as other people), and (3) deterioration of cognitive function and personality: temporary impairments in perception, cognition and control of motor impulses, difficulties in thinking, feelings of bewilderment, puzzlement, and confusion (Mawson, 2007).

According to Ma et al. panic prone individuals include: children, females, elderly, mobility impaired, those with strong beliefs, have poor knowledge, experiencing fatigue and weakened perception (Ma et al., 2011). Necessary conditions for panic to occur include: (1) a confining environment produced by structure, dark environment, or the crowd itself, (2) beliefs on the potential danger, and (3) triggers such as an earthquake or fire (Ma et al., 2011).

Many experts believe that mass panic is rare in disasters, largely a myth and unsupported by evidence (Cocking et al., 2007). Ma et al. however claim that panic exists in crowd disasters (Ma et al., 2011). Panic can be helpful in triggering flight allowing an individual to immediately seek shelter, the nearest exit and head to a safe area. Alternatively, it can be deadly, for example when the individual freezes delaying evacuation.

Social attachment can regulate fear and panic, thereby affecting evacuation behaviour. For example immediate flight is delayed when attachment is triggered such as seeking a relative or getting belongings. It can facilitate the flight of a calm parent upon hearing the cries of a crying child in panic (Heath et al., 2001).

Attachment Theory - Human beings as described by Bowlby have innate attachment behavioural systems motivating them to seek proximity to significant others (attachment figures) during times of need or threat (Bowlby, 1982; Ainsworth, 1989; Mikulincer and Shaver, 2007; Beckes and Coan, 2015). Attachment styles are described as

Table 3. Attachment figures and possible behaviours during evacuations

Attachment Figure	Examples	Example behaviour	Sources
Person	Child, spouse, parent, sibling, kin, friend, colleague, leader, mobility impaired, stranger	Seeking, calling, checking on the whereabouts, following, leading, helping, rescuing	(Jon et al., 2016; Averill et al., 2005; Drury et al., 2009)
Group	Family, relatives, friends, colleagues, authorities, crowd	Reuniting with members, following group (decision, direction), relocating to group's home, herding, , flocking	(Averill et al., 2005; Prati et al., 2012; Daamen, D. C. Duives, et al., 2014; D'Orazio, Quagliarini, et al., 2014)
Object	Personal property	Recovering personal property	(Averill et al., 2005; FSF, 2004)
Place	Home, exits, entrance, pathways, routes, designated safe area, elevator	Returning home, take familiar routes, head towards entrance, known exits/safe areas	(Jon et al., 2016; Prati et al., 2012; Cocking et al., 2007; Averill et al., 2005; D'Orazio, Quagliarini, et al., 2014)
Animals	Pets, farm animals	Staying home with pets, evacuating with pets	(Heath et al., 2001)
Task	Work, routine, driving, sleeping	Continuing with current task, getting luggage before evacuating aircraft during emergency	(Averill et al., 2005; FSF, 2004)
Information	News, announcements	Seek from conversations, radio, email, social media, etc.	(Averill et al., 2005; D'Orazio, Quagliarini, et al., 2014)

being secure, avoidant or ambivalent (Bretherton, 1994; Bowlby, 1982; Bowlby, 1988). Presence of attachment figures results in relieving and reducing stress and provides a sense of security (Ainsworth, 1989). Also, threats make individuals more aware of their attachment to a place and may influence decisions to stay or evacuate during dangerous situations (Anton and Lawrence, 2014). Attachment figures during evacuations are presented in Table 3.

Social Attachment Theory - Social attachment theory is based on Bowlby's attachment theory and is used to explain disaster scenarios. According to Mawson the response to a variety of threats and disasters is not to flee or attack but affiliation, or seeking the proximity of familiar persons and places, even if this involves approaching or remaining in a situation of danger (Mawson, 2005). Mawson also states that separation from attachment figures is a greater stressor than the physical danger itself. Whereas the presence of familiar persons and places have a calming effect.

Mawson argues that, this may provide an explanation of several evacuation behaviours such as the slow reaction of individuals within groups to warnings, delay in leaving work areas, and waiting for social group members before evacuating, and seeking family members.

The central ideas of this theory are: (1) the dominant motive in disasters is to maintain proximity to familiars, (2) flight involves the movement away from danger and towards people and places viewed as familiar, (3) flight-and-affiliation depends on perceived danger and social context (i.e. location and activities of familiars), (4) fear is diminished by proximity to attachment figures, (5) when an individual is close to attachment figures, in the presence of threat, intense affiliation behaviour is triggered, and does not cause flight, (6) moving as a group to maintain proximity during flight, (7) mild threats can induce flight-and affiliation behaviours when individuals are alone or with strangers (Mawson, 2005).

According to Mawson, there are four possible outcomes of individual and collective reaction to threat and disaster, presented in Table 4. (1) Top left: when attachment figures are present and the perceived degree of danger produces mild anxiety, affiliation is triggered producing increased attachment. Individuals tend to seek the proximity of familiar people and locations. (2) Bottom left: when attachment figures are present, and perceived danger is severe producing fear or terror, occasional or low-to-intense flight and affiliation is triggered resulting in orderly evacuation.(3) Top right: when attachment figures are absent, and the perceived degree of danger is mild, this

Table 4. Affiliative reactions to threat (Mawson, 2005)

		Attachment Figures (Predisposing Conditions)	
		Present	**Absent**
Perceived Degree of Danger (Precipitating Conditions)	**Mild Anxiety**	Affiliation (Increased attachment), Seek proximity with familiar people and locations	Low intensity Flight-and-Affiliation, orderly evacuation away from danger and towards the familiar
	Severe Fear/Terror	Occasional low-to-intense flight-and-affiliation; orderly evacuation	Intense flight-and-affiliation; mass panic

triggers low intensity flight-and-affiliation, resulting in orderly evacuation away from danger and towards the familiar, and (4) Bottom right: when the attachment figure is absent, and the perceived degree of danger is high, intense flight-and-affiliation is triggered resulting in mass panic.

Evacuation behaviours that can be explained by social attachment theory include: (1) individuals with close ties seeking each other and evacuating as a group, (2) movement to familiar exits and doorways (entrance), (3) delayed evacuation start (departure), (4) slow evacuation speeds, (5) slow reaction to warnings and waiting for primary group members, (6) reluctance to leave ones home, (7) preservation of social organisation, (8) mutual aid and cooperation, (9) calmness during evacuation, (10) going home, (11) seeking other survivors (formation of groups), and (12) reuniting with familiar people and surroundings (Mawson, 2005).

Cocking et al. identify the strength of social attachment theory over the panic model to be its emphasis on the maintenance of social bonds and the co-operative nature of groups during disasters (Cocking et al., 2007). Cocking and colleagues however identified two main drawbacks: (1) the pessimistic implications for large groups as it is more difficult to ensure safe evacuation of all group members; and (2) it discounts the possibility of developing attachment bonds and the eventual co-operation between strangers.

Social Baseline Theory - This theory provides the neuroscientific explanation as to why humans form social ties and seek proximity (Coan, 2008). Beckes and Coan believe that human brains assume proximity to predictable social environments, and when proximity is maintained or re-established, the brain is less vigilant for detecting potential threats (Beckes and Coan, 2011). Also from the same authors, humans utilize social resources or social proximity to conserve costly cognitive resources through social regulation of emotion. This includes the distribution of the task of detecting environmental risks across individuals within groups, inter dependence in achieving goals and providing help during times of need.

Social Defense Theory - extends Bowlby's and Mawson's attachment theories. Ein-Dor et al. claim that having some secure, anxious and avoidant members in a group provides unique survival advantages (Ein-Dor et al., 2010). Secure individuals are good leaders and are best at coordinating tasks. They are however slower to react to dangers because of proximity seeking behaviours. Anxious individuals are fast in detecting and reacting to danger and can act as sentinels of groups. Avoidant individuals are accustomed to looking out for their own interest and more likely rely on self-protective fight-or-flight reaction in times of danger. Primarily motivated to save themselves, they are the first to open exits, break windows and can define routes for others in the group to follow. This theory may help to explain the different behaviours found in a group of individuals.

Self Categorisation Theory - refers to the process where a person categorizes oneself as an individual or a group member involving a process of de-personalisation where the individual stereotypes themselves in line with the group. This process or self-categorisation as a group member makes crowd behaviour possible (R. H. Turner and Killian, 1987) resulting in a physical crowd of individuals who only share physical location; and the psychological crowd where people act together. Social behaviour observed in emergencies is a consequence of emergent self-categorisation rather than a function of pre-existing bonds, prior interpersonal relationships or interactions (Drury et al., 2008; Daamen, D. Duives, et al., 2014). Also, from the same study, this makes individuals transition and adapt to become part of a psychological crowd useful in surviving mass emergencies and disasters. This differs from self defense theory in that self categorisation theory focuses on a person identifying with a group rather than characteristics of individuals in a group.

Social Identity Theory corrects the limitation of the social attachment theory in the explaining behaviour with unfamiliar people, objects and places. Social attachment theory suggests that people may display panic behaviour

Table 5. Theories on Affiliation

Sources	Theory	Idea	Behaviour
(Chu, Pan, et al., 2011)	Normative	Social norms and bonds persist during disasters, social structure is retained	Normal, helping, cooperation
(B. E. Aguirre et al., 1998)	Emergent Norm	Dissolution or suspension of existing norms, creation of new norms (non traditional) from social interaction	Non-traditional/Illogical
(Mawson, 2005; Strauss, 1944; Drury et al., 2008; Ma et al., 2011; Helbing and Johansson, 2013)	Panic	Breakdown of existing bonds and norms (social and cultural)	Herding, irrational, selfish, disorderly and competitive
(Bowlby, 1982; Mikulincer and Shaver, 2007)	Attachment	Bond formation from childhood developed towards adult life	Proximity seeking
(Mawson, 2005)	Social Attachment	Activation of attachment bonds during threat	Proximity seeking, cooperation
(Beckes and Coan, 2011)	Social Baseline	Instinctive development of social bonds to maximize social resources and distribution of risk	Proximity seeking, cooperation, sentinel
(Ein-Dor et al., 2010)	Social Defense	Variation in attachment styles between groups is optimal to ensure survival during disasters	Leadership, cooperation, sentinel, anxious
(R. H. Turner and Killian, 1987)	Self Categorisation	Individuals' transition to become members of the psychological crowd, shared fate	Cooperation
(Drury et al., 2009; Sivers et al., 2016; Tajfel and J. C. Turner, 1986)	Social Identity	Development of bonds between strangers in unfamiliar locations and disaster situations	Helping

when with strangers. This is contrary to observed helping behaviour among strangers during disasters. Social identity theory accounts for the development of bonds between strangers in unfamiliar places precipitated by events. Shared social identity increases supportive behaviour and coordination during emergency situations (Drury et al., 2009). Helping behaviour such as aiding the elderly and injured individuals or rescuing people under rubble can be explained by social identity theory.

A summary table of the theories is presented in Table 5. It can be concluded in this section that social attachment can influence evacuation behaviour during disasters and crisis events. Each theory provided an explanation on how attachment influences evacuation behaviour. However a full explanation of this influence can not be attributed to a single theory but a combination of each idea presented to get a full understanding of this effect. Also, the effect of culture on attachment behaviour needs to be considered. Reactions of individuals to disasters can vary between cultures and result from different attachment styles influenced by their unique socio-cultural contexts (Rothbaum et al., 2000; Marsella and Christopher, 2004; Otto, 2008).

AGENT BASED MODELS OF SOCIAL ATTACHMENT

Agent based models have been implemented to simulate human behaviour during evacuations. Some models are implemented guided by data from observations and surveys. Social theories used in most models are often not explicitly stated. We will try to show in the following models how the previously mentioned theories are used to model agent behaviour.

Social Force Model - models pedestrian behaviour during panic and normal situations (Helbing, Frakas, et al., 2002). Repulsive and attractive forces define the relationships between agents. Attractive forces can represent the close bonds between family members, or pull of a safe area. Panic and herding behaviour are observed. Roan (Roan, 2013) implements a modified version of the social force model and simulated trampling during stampedes. Herding and trampling during stampedes shows panic and emergent norm theories at work.

Earthquake Pedestrian's Evacuation Simulator (EPES) models pedestrian (children, adult and disabled) behaviour during an earthquake (D'Orazio, Quagliarini, et al., 2014). Social attachment theory is implemented through the bonds that maintain cohesion in pedestrian groups (clans), and the attraction to safe areas. The social force model is modified to reflect panic and conditions during an earthquake. Herding and collision avoidance are replicated in the model.

Evacuation Simulation with Children, Authorities, Parents, Emotions, and Social Comparison (ESCAPES) is an airport evacuation tool implementing social attachment with different agent types, and emotional, informational and behavioural interactions implemented with the Belief, Desire and Intention architecture (Tsai et al., 2011). Agents include travellers, families and authorities. Interaction between agents include: spread of knowledge, emotional contagion and social comparison. During evacuations, parents immediately seek to gather their family before proceeding to an exit, children exclusively follow their parent and travel slower. (Tsai et al., 2011)

Exitus focuses on the evacuation behaviour of individuals with mobility impairments (Manley, 2012). Agents include non-disabled, motorized and non-motorized wheelchair users, visually impaired, hearing impaired and stamina impaired. Social attachment theory is implemented through agent bonds resulting to seeking and helping behaviours.

Multi-Agent Simulation for Egress Analysis (MASSEgress) simulates individual behaviour through sensing, decision making, behaviour selection and motor control. Interaction between agents define social behaviour. Panic and emergent norm theories are implemented resulting in queuing, competition, herding, and leader following behaviours (Pan, 2006).

Social Agent for Egress (SAFEgress-2014) implements social attachment theory and models occupants affiliated to social groups, defined by a unique structure and group norm (Chu, Parigi, et al., 2014). Factors implemented include group intimacy, leadership and separation distance. High-intimacy groups include couples or families. Low-intimacy groups can represent co-workers.

Social Agent for Egress (SAFEgress-2015) - implements the social attachment theory by modelling evacuation of social groups, and emulating human capabilities of perception and navigation (Chu, 2015). Different agent behaviours modelled include: (1) following perception to evacuate; (2) following knowledge to evacuate; (3) navigating with group members; (4) navigating with entire social group; (5) following the crowd to evacuate; and (6) following authority's instructions.

Social Identity Model Application (SIMA) - implements the social categorisation and identity theories with the focus on helping behaviour. It has two main components implemented in sequence: social identity (establishing social identity), and helping behaviour. Pedestrians who do not share a social identity with a group head straight for safety without caring for others (Sivers et al., 2016).

Okaya and Takahashi's, RoboCup Rescue Simulation - is an evacuation based on the BDI architecture and Helbing's agent behaviour model and developed using the RoboCup Rescue Simulation v. 1 (RCRS) platform (Okaya and Tokahashi, 2011). Agents in the model are adults, parents and children. Results showed delayed evacuation times for parents who take care of their children. The results of evacuation simulations reveal (1) family members evacuate together; (2) guidance during evacuations affects crowd behaviours; and (3) evacuation takes more time when congestion occurs. This model implements the attachment and social attachment theories.

Lou, et al.'s Model - is a simulation for normal and emergency scenarios for a Singapore train station (Luo et al., 2008). Social group and crowd related behaviours are modelled from social psychology, such as social attachment theory. Individual agents are categorized into roles as staff, civilian, or tourist; age group: child, adult, or elderly; on social relationship: strong tie, normal tie, or individual; and based on personality: altruist, common person, or avoidantist. Behaviours include: wander, flock, evade, lead, follow, seek, individual escape, group escape, idle, help, and run aimlessly. In the normal situation, people wander individually or as a group.

STEPS by Mott MacDonald Ltd is a microsimulation tool for pedestrian movement and can be used for normal and emergency conditions (evacuation mode) (Waterson and Pelliser, 2010). Agent attributes include free walking speed, awareness, patience, association to other members of a family group and pre-movement time. This model implements the social attachment theory.

Wang et al.'s Model developed an optimisation method for emergency evacuation and considered social bond effects (Wang et al., 2009). They considered the disorder and blocking effects caused by social bonds during evacuations. According to them, close bonds such as with family members and familiar colleagues in a company help keep order in evacuation. This is manifested in queuing behaviours making evacuations smooth and efficient. Loose bonds between unfamiliar individuals can increase competitiveness resulting in pushing and shoving behaviours triggering disorder, blocking and delay in the evacuation. This model implements the social attachment theory.

A summary of the models is shown in Table 6.

Table 6. ABM implementing social attachment during crises

Source	Implementation	Theory	Agents	Behaviour
(D'Orazio, Quagliarini, et al., 2014)	EPES	Social Attachment, Panic	Pedestrian (child, adult, disabled), clan	Herding
(Tsai et al., 2011)	ESCAPES	Attachment, Social Attachment	Family members, travellers, authorities	Follow Parent, Drag into Shop, Find Child, Find Other Parent
(Manley, 2012)	EXITUS	Attachment, Social Attachment	Nondisabled, motorized wheelchair users, nonmotorized wheelchair users, visually impaired, hearing impaired, stamina impaired	Helping
(Luo et al., 2008)	Lou et al.	Social Attachment, Social identity	staff, civilian, tourist, child, adult, elderly	Wander, flock, evade, lead, follow, seek, escape (individual, group), idle, help, run aimlessly
(Pan, 2006)	MASSEgress	Panic, Self Identity	Individuals	Competition, queuing, herding, leader-follower
(Okaya and Tokahashi, 2011)	Robocup Rescue	Social Attachment	Adult, parent, child	group evacuation, guidance
(Chu, Parigi, et al., 2014)	SAFEgress (2014)	Social Attachment	Family, couple, co-worker	Group evacuation
(Chu, 2015)	SAFEgress (2015)	Social attachment	Building occupants	Navigating with group, following (crowd, authority)
(Sivers et al., 2016)	SIMA	Social Identity, Self Categorisation	Pedestrians	Helping
(Helbing, Frakas, et al., 2002; Helbing and Johansson, 2013; Roan, 2013)	Social Force	Panic, Emergent Norm, Social attachment, Normative	Pedestrian, family	Panic, herding, trampling, queuing, cooperation, self organisation,
(Waterson and Pelliser, 2010)	STEPS	Normative	Family	Walking, association
(Wang et al., 2009)	Wang et al.	Social attachment	Family	queuing, pushing and shoving

CONCLUSION AND FUTURE WORK

In this paper, we have shown that attachment bonds are activated by threat during disasters and regulate the instinctive selfish flight behaviour, pushing the individuals to consider others instead. Indeed, individuals seek the proximity of attachment figures for security and comfort, while their absence produces more anxiety than the threat itself. The social nature of evacuations (facilitating or delaying them) and the impact of attachment on mobility makes it important to model social attachment.

We have presented several theories to explain the role of attachment in human mobility. Each theory offered a piece of the puzzle, a unique perspective in explaining different behaviours during evacuations. This provides us with a strong foundation to build agent-based models for crisis scenarios. Agent-based models of evacuation already exist that have integrated social and psychological aspects of human behaviour, but they usually lack in accounting for group dynamics and strong ties. Social attachment bonds have been implemented by some simulations of egress behaviour, but there is room for improvement of their realism.

We argued that the BDI multi-agent architecture provides an opportunity to integrate attachment bonds in human agents' beliefs, desires and intentions during crisis situations. The ideas discussed in this paper lay the groundwork for the development of our multi-agent model and simulator of the influence of social attachment on human evacuation behaviour during seismic crises. This model will be used to experiment with different disaster evacuation scenarios and observe the resulting behaviours of a simulated population of agents. The goal is to study the impact of different demographic features and attachment strengths and styles on human mobility during evacuation. Results will be compared to those obtained by previous studies.

ACKNOWLEDGEMENT

This research is supported by funding from Rhône Alpes Region, France, ARC 7.

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Integrating Human Factors into Evacuation Simulations - Application of the Persona Method for Generating Populations

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ABSTRACT

For assessing evacuation dynamics in disaster situations, current approaches of pedestrian simulations increasingly include additional human characteristics. One aim is to assess realistic effects of structural changes of an infrastructure on evacuation behavior displayed by users. Creating agents with supplementary physical and psychological human characteristics and assembling the agents in accordance to the user's population may be beneficial not only to support decision making. The analysis of simulated effects of, e.g., informational strategies will foster crisis and disaster management.

This paper combines knowledge about users in subway systems and highlights benefits of using the Persona method to improve objectivity in the specification of different user types. Persona method is adapted to pedestrian simulation. Using data from the authors´ field studies, personas are developed and implemented for an evacuation simulation. First findings suggest that including personas into pedestrian simulation influences the results with respect to the required safe evacuation time (RSET).

Keywords

Persona method, pedestrian simulation, preparedness, human factors, evacuation.

INTRODUCTION

This article results from a cooperation of researchers from different research domains: Researchers of software engineering, psychology and pedestrian simulation integrated their knowledge to build personas of relevant evacuees in subway systems. Apart from the theoretical discussion, the fusion of research perspectives was an additional challenge. A common language was necessary to bridge the different researchers´ points of views and the theories of each research domain, and to enable a shared understanding of data and options for this kind of implementation. Further research will be conducted to gain further knowledge by this cooperation.

The Persona method is a descriptive model describing users' needs, behavior and motivation (Cooper et al., 2007). Persona method has its origin in user-centered design and marketing and is adapted to pedestrian simulation. Personas are not real people but they represent a powerful tool to represent users in a design process. Personas usually are presented in a narrative description and are based on research work and ethnographic studies taken the respective end-user of a product into account. In this paper, the data is taken from field studies in a subway system in Germany.

The aim behind creating Personas, and as a result to build up successful products, is to design not for a variety of users but rather to specify your product with regard to specific needs of a specific type of group of individuals (according to Cooper (2007)). Personas can help to keep the users' perspective in focus of a development process. This knowledge is used as a foundation for plans to create products whose form, content, and behavior is useful, usable, and desirable, as well as economically viable and technically feasible to the end-users in focus.

Personas are to reveal all relevant user types of a product, e.g. originally Persona was used for the product of software. In this paper, instead of designing a software the Persona method is used to account for behavior in interactive environment systems with the goal to assess the "product: Evacuation design in subway systems". By means of Personas, all relevant characteristics of possible occupants of a subway system are to be integrated, in order to answer the following questions: What are relevant physiological and psychological characteristics of occupants for an evacuation scenario? Which characteristics need to be implemented in pedestrian simulations in order to receive realistic evacuation times? Which occupant characteristics have to be considered for effective evacuation design of subway systems?

In the following the consecutive and mandatory steps to create personas according to Cooper (2007) are described in the context of simulation. This process includes the identification of relevant human characteristics of pedestrians. Secondly, it is highlighted which occupants of a subway infrastructure are clustered into subgroups thereby forming separate personas. The personas are specified using data in an evacuation scenario in a subway station. In a third step, the Persona method is utilized for generating occupant scenarios. It is implemented in pedestrian simulation demonstrating the application by using JuPedSim (Kemloh Wagoum, 2015). The subsequent simulations are also conducted with JuPedSim. Based on the results, it is discussed which improvements can be reached using Persona and how efforts can be minimized by creating subsets of personas, e.g. according the purpose of a simulation.

HOW TO CREATE PERSONAS

The process to create personas is described in Cooper (2007). The complete approach to create personas includes seven steps (Cooper (2007), p. 97ff). In the following part of this chapter the different steps are presented and one additional step is suggested, if personas are to be used for the purpose of evacuation design in subway systems rather than in software design (see also Ontology of Personas Ontology in the References).

STEP 1: Identify Behavioral Variables

Cooper (2007) lists three kinds of individual variables: I. geographic variables (as part of demographic variables) II. demographic variables, and III. behavioral variables. The process of constructing personas is focused on the behavioral variables because they are more useful in the description of interactions with a product. Thus, based on data and information gathered on the desired end-user behavioral variables are to be identified.

Nonetheless, for the purpose of this paper, all three individual variables are introduced first:

I. Geographic Variables

For a desired product, a specification of the setting in which personas act is highly relevant. In this paper, the persona is not meant e.g. to sit in front of a computer using a software but to be an occupant in a subway system. The subway system is located in Berlin, Germany and the person has to evacuate from the latter. For the evacuation design in subway systems, also the location of a persona within the subway station is relevant. The location may also address the reason for being within the infrastructure (e.g. shopping, commuting) and further qualities of the environment (e.g. visibility, walkability, availability of oxygen, availability of lifts), both in general usage and especially during evacuation (e.g. if stairs are blocked by debris even an unhandicapped persona may not be able to evacuate on her own). Therefore, this consideration of geographic variables differs from the original approach of Cooper (2007). Thus, these variables have to be considered separately from the demographic variables.

II. Demographic Variables

Cooper (2007) lists the name (suitable for a specific persona), age or gender. Further important demographic variables for the usage of personas for evacuation are: height, weight and walking speed of the respective user. Moreover, the personas general group membership and family status influence reactions and behavior during evacuation. Furthermore, the profession or occupation is considered relevant, as this might influence perceived tasks during evacuation, e.g. paramedics might feel obliged to support harmed occupants; safety staff from the infrastructure may give directions before leaving the station; a shop owner may close down before leaving his/her shop. Another demographic variable is nationality, due to the fact that cultural norms and the procedures regarding evacuation may influence and determine acceptable behavior, e.g. following others, acceptance of support by others, aspects of proximity, or gender roles.

III. Behavioral Variables

In order to cover all types of behavior, Cooper (2007) distinguished between five different kinds of behavioral variables: a) activities, b) attitudes, c) aptitudes, d) motivation, e) skills. The authors adopt the same distinction except for the description of aptitudes (see Table 1 below).

Activities refer to what the user does (frequency and volume). For personas in the context of evacuation these activities include:

- Primary reason for presence in the station (e.g. shopping, commuting, under passing the street level), which may depend on the time of day (e.g. opening hours of shops; peak hours for commuters).
- Target: targets could be “local goals”, e.g. a specific shop, exit, or platform. Targets may, on a more global level, refer to the ICE-Phases (cf. e.g. Gwynne and Kuligowski, 2010). For the subway station this would refer to: Ingress from street level, Circulation inside the station on distribution level with shops and/or platforms, and Egress from the subway station to the outside/ towards street level. This second differentiation is relevant because evacuation simulation usually assumes a maximum of users that is egressing. In reality, people do not egress immediately; some may continue to circulate to their local goal, as others might ingress the station (see e.g. Gwynne et al., 2016; Künzer, 2016; Pretorius, 2015).
- Additional activities added to Cooper´s (2007) concept by the authors are group affiliation (how much is a persona attached to other people), and (perceived) group coherence (in how far is a persona accepted as part of a group). Linked to the more general status of group membership as part of demographic variables, affiliation refers to the accompanying group/ family in the context of the product.

Attitudes refer to how the user thinks about a product domain and technology. For the product: Evacuation design in subway systems, attitudes are differentiated into the following aspects (each of them defined on separate dimensions – including the dimensions on the left or right, a persona can occupy only one (intermediate) characteristic on each continuum):

- Affective State: Feeling, Mood, Emotion, perceived safety in the station, fatigue
    - Perceived safety: not safe at all ⟷ very safe
    - Emotion: fearful ⟷ fearless
    - Perceived level of fitness: exhausted ⟷ well rested
    - Tiredness and fatigue: tired/ unconcentrated ⟷ awake/ concentrated

Aptitudes refer to the education and training of a user and the capability to learn. Because it is hard to determine the knowledge about evacuation in general (How am I supposed to act?) and the application of this knowledge (How will I act?) this differentiation is only partly relevant for the implementation. Due to methodological constraints, scientific insights in aptitudes of people during evacuation are missing. For the purpose of building personas for evacuations, capabilities of occupants are subsumed under Cooper´s (2007) skills-category, even though he lists capabilities originally under aptitudes. Furthermore, in the authors´ field studies there was a discrepancy between “participants´ statements on what they would do” and “the behavior they displayed during a `pseudo´-evacuation during the field studies”. The psychological distinction of capabilities (could act like this) and skills (applying the knowledge in order to act) are adopted instead.

Motivation refers to why the user is engaged in the product domain. For the product of evacuation different aspects are described on individual dimensions:

- Strategies and preferences: Strategies of wayfinding/ route choice/ obeying to orders, ...
- Application of different strategies for route choice: even if not done consciously, people apply certain strategies to find the safest route (e.g. Andresen et al., 2016); the route choice “no strategy” would be inappropriate and can be considered closest to the following “trial and error”:
    - Trial and error: low ⟷ high
    - Shortest path: low ⟷ high
    - Quickest path: low ⟷ high
    - Avoid jamming: low ⟷ high
    - Following exit signs: low ⟷ high
    - Take next possible way up: low ⟷ high
    - Follow other persons: low ⟷ high

- Well-known paths: low ⟷ high
- Obeying to orders: low ⟷ high
- Obedience: disobedient ⟷ obedient

- Cooper (2007) distinguished three different types of goals to characterize a baseline of a persona: experience goals, end goals and life goals. In relation to the context of the product “Evacuation design in subway systems” the original aim of the goals have to be changed slightly. Persona should feel as comfortable (or as safe) as possible during an evacuation (experience goal). Personas should be aware of upcoming problems along their evacuation route (end goal) and succeed the evacuation process (life goal). These overarching goals are similar for each persona but strongly differ in the details. In the context of evacuations experience might play a crucial role and therefore the experience goals are the focus of this paper. A Persona may have an experience goal: e.g.: never did anything happen, thus I will not evacuate instantly and continue what I am doing presently (shopping, waiting for/ boarding a train). The defined continuum is:
  - Continue to do present activity ⟷ evacuate (reestablish safety, control)

Skills are a user´s capabilities related to the product domain and technology. The authors specified this aspect for this research as:

- Physical resources (is a person able to participate in evacuation: general fitness, health, physiological characteristics, special need/ disabilities):
  - Needs support (by others or technology) ⟷ evacuates by him/ herself
- Generalized knowledge (knowledge about and experience with evacuations; subway systems, …):
  - Low frequency of use of subway systems ⟷ high frequency of use of subway systems
  - Unexperienced with subway evacuation ⟷ very experienced with subway evacuation
- Local knowledge (specific knowledge on and experience with evacuation from subways, with the subway station (geometry, location of lifts), with safety in subways)
  - No local knowledge ⟷ complete local knowledge

STEP 2: Map Interview Subjects to Behavioral Variables

Based on the identified variables and insights about the user of evacuation routes, a mapping of demographic and interview data from previous research in line with the behavioral variables is conducted. One example for positioning individual people on a continuum for individual local knowledge (behavioral variable: skills) is shown in the figure below (cf. also Schäfer et al., 2014). Passengers with the same level of local knowledge may later be subsumed in the same persona.

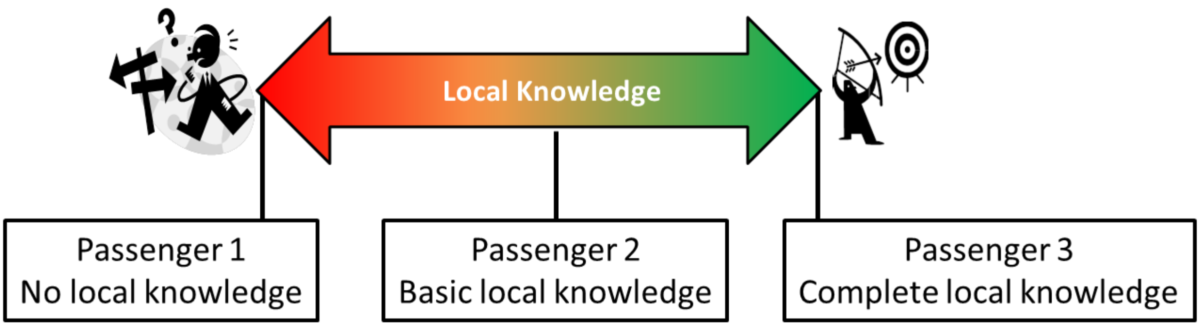

Figure 1. Classification of Passenger Types on a Continuum for Local Knowledge

STEP 3: Identify Significant Behavioral Patterns

In order to identify behavioral patterns, insights about the combination of different variables were necessary, e.g. evacuation strategies arise due to a walking disability of a respective person and therefore limit the scope of action for the person or the need for help in an evacuation due to the disability. For a useful pedestrian-level simulation model, identifying significant behavioral patterns should furthermore include aspects such as identifying which paths are usually taken or used by users when entering the infrastructure. Users may be familiar with these paths and may preferably use them in case of an evacuation. Apart from using interviews, data can be gathered by observation of users´ behavior within an infrastructure.

STEP 4: Synthesize Characteristics and Relevant Goals

Step 4 synthesizes characteristics and relevant goals of a persona. Attributes were combined to specify and detail the different personas from the data gathered. Sticking to the behavioral variables mentioned above, a certain persona is described through a combination of variables of Step 1 (see Table 1).

Table 1. Overview of demographic and behavioral variables and further attributes of three personas.

Variables/ Characteristics		Personas:		
		Peter Elderly, with walking stick	**Johanna** commuter	**Anna** School child, not yet young adult
Demographic Variables	Nationality	German	German	German
	Age	71	45	12
	Gender	male	female	female
	Group membership	individual	individual	individual
	Family status	married	solid relationship	single
	Profession	retiree	banker	student
Behavioral Variables – Activities	Primary reason for presence in the station	commuting between home and shops	commuting between work and home	commuting between school and home
	Group affiliation	low	low	low
Attitudes	Affective state	fearful	rested, in a hurry	fear and curiosity
Motivations	Strategies and preferences	well known path	shortest path; quickest path	follows other people; well known path, trial and error;
Skills	Physical resources	needs help (escalator, lift; due to walking stick)	evacuates herself without help	might need help

STEP 5 to STEP 7: Check for Completeness and Redundancy, Expand Description and Designate Persona Types

After the identification of relevant combinations of variables, the behavioral pattern and the conceptual design of the personas are checked for redundancy and completeness. Given that in the course of an evacuation, individual characteristics could change, e.g. a group could fall apart or be separated; the individual may now be regarded as a different persona with other attributes. By looking at the phases following the initial request to leave the station, further attributes and possible combinations of them were added creating additional personas.

Consequently, in step six according to Cooper (2007), an expanded description of attributes and behaviors was formulated. Per definition, the identified groups are thus clearly separated from each other as personas. In the seventh and final step the persona types are designated and now receive a name. Ideally, a sketch or even a picture of that persona is added to it´s characteristic variables. Three different examples for personas for the given subway station can be found in Table 1, containing an overview of demographic variables and behavioral variables and further attributes for each of the three personas. For limitations in the length of the table, only a selection of variables and attributes is presented here.

STEP 8: Implementation of Personas

The "translation" of personas into a machine-readable format is included in the work of Cooper (2007). Depending on the intended use in a computer software, the description of the personas has to be transformed for a direct use in an application. Different types of formats exist with deviating semantic richness. An ontology contains a very high semantic richness and is able to cover many aspects of a persona (cf. Ontology of Personas in the References). At the same time the choice of the semantic richness depends on the software application as it might not be able to handle the semantic richness of the personas originally defined. The following figure (from McGee and Greer, 2009) demonstrates the various possibilities.

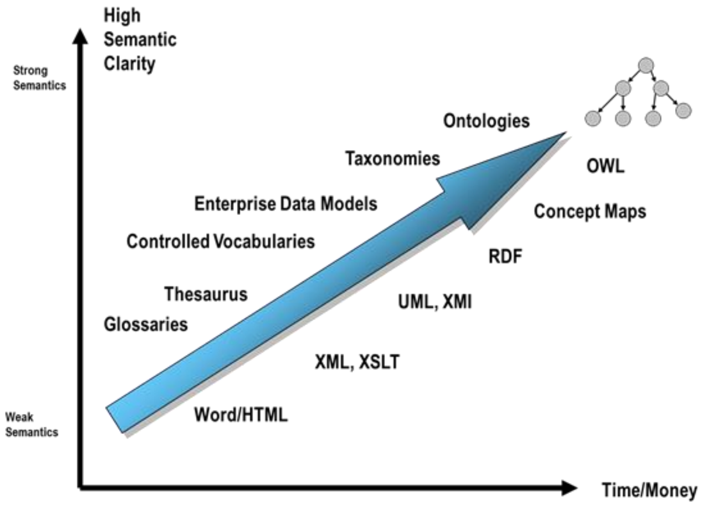

Figure 2. Overview of Machine-Readable Formats with Rising Semantic Richness

Regardless of the timely efforts, an ontology described in a web ontology language (OWL) would be a desirable form for describing semantically rich personas in a machine-readable format. The work of Negru (cf. References for URL) shows one realization of the Persona domain in an ontology. By this he follows the definition of Goodwin (Goodwin, 2005) to clarify his understanding of personas: A persona is regarded as a user archetype which can be used to "help guide decisions about product features, navigation, interactions, and even visual design". Even if the purpose of the ontology differs from the purpose of the authors of this paper, it helps to find solutions for the translation process from narrative to formal descriptions, to finally use the persona in pedestrian (evacuation) simulations.

For demonstration purposes, selected personas with limited behavior patterns were used in the case study described in the next paragraph.

CASE STUDY

The implementation of the persona method into a pedestrian simulation will be demonstrated based on a rather simplified evacuation analysis conducted for a subway station. For this purpose, the JuPedSim framework is applied. In order to focus on selected research topics, the intention of the latter is to provide scientists with an open-source software environment, which supplies the basic utilities for pedestrian simulation. The framework currently consists of JPSeditor (setup of geometries), JPScore (computation of trajectories), JPSvis (visualization), and JPSreport (post-processing). Further reading is provided in (Kemloh Wagoum, 2015).

Geometry and Scenario

The following simulation study refers to an existing subway station in Germany, which is the centerpiece of the current ORPHEUS research project (cf. references for homepage URL). The station consists of two platform levels and one overlying concourse level, which also comprises retail spaces (see Figure 3). It is noteworthy that all egress paths towards the surface traverse the concourse level. The latter is connected to the surface by five staircases (exits: A, C, D, E, G). The surface is predominantly covered by an intersection of two arterial roads including multiple bus stops and one tramway station.

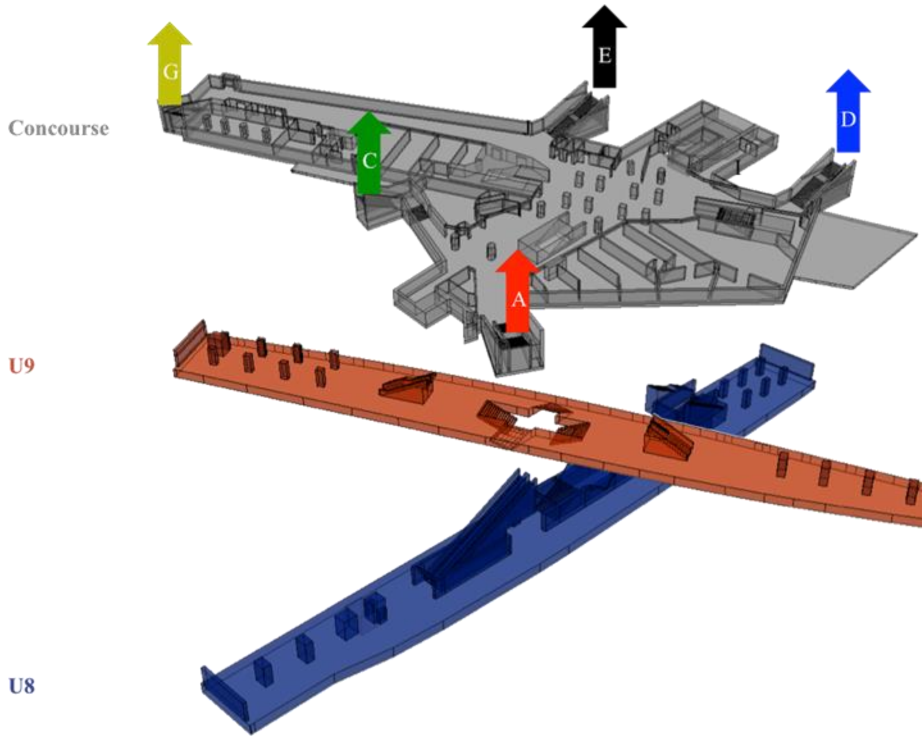

Figure 3. Subway Station Consisting of Two Platform Levels and One Concourse Level

The focus of this study is set to the population characteristics. Hence, additional considerations regarding the occupant scenario have a simplified extend. It is assumed that an evacuation alarm is triggered via the public address system (loudspeaker announcement). With regards to protective active decision model (Kuligowski, 2016), no further evacuation cues e.g. staff intervention, behavior of others, or traces of fire, gas or explosives are considered.

Population Generation and Implementation of Personas

Pedestrian simulations are commonly set up with representative populations, whose major characteristics (walking speeds, body sizes etc.) are described by distributions. In order to put emphasis on both heterogeneity and the dynamical composition of populations, the major objective of this study is to describe the latter by a bottom-up approach. For this purpose, the above-mentioned formulation of personas has been condensed to a set of three personas (see Table 1) including parameters, which can be yet implemented into pedestrian simulations (see Table 2). Please note that these specifications represent a very simplified excerpt out of the analyzed field data [e.g.: 12, 13]. As the pedestrian simulation considers male and female in equal proportions of the population, and because gender did not matter significantly for the findings from previous field studies, a persona with identical characteristics is assumed for both male and female regardless of the gender specification in Table 2.

Table 2. Preparation of Personas for Pedestrian Simulation for the Specific Subway Station

Commuting persona Variables/ characteristics	Anna	Johanna	Peter
Age-group, gender	Youth, female	Adult, female	Elderly, male
Walking speeds μ / σ [m/s] Plain/ upwards stairs	1.6 / 0.3 0.86 / 0.26	1.48 / 0.3 0.80 / 0.26	1.07 / 0.2 0.58 / 0.25
Shoulder width [m]	0.3	0.42	0.38
Pre-movement times [range in s]	[90, 180]	[0, 180]	[180, 240]
Preferred exits of subway station	A, C, E	Shortest path A, C, E	Shortest path

Having available these personas, the information is then transferred to machine-readable format, which is XML in this study. The subsequent step is to generate populations out of the latter. In principle, this process has been split up into three steps: (1) composition, (2) relative passenger load, and (3) population size.

Initially, the population composition has been defined by constraints regarding the fractions of the personas throughout the daytimes. Unfortunately, there is only few data available about population composition ratios and the latter heavily depends on the location, demographics or adjacent infrastructures (see e.g. Spearpoint and MacLennan, 2012). In order to account for these uncertainties, upper and lower temporal constraints have been defined as exemplary shown in Table 3. These assumptions were based on the qualitative findings regarding the general passenger mix in public transportation provided in (Weidmann, 1994).

Table 3. Excerpt of Percentage Constraints for Population Composition throughout the Day

Daytime / Age	Youth		Adult		Elderly	
04:30 am	0	10	90	100	0	0
08:00 am	10	30	60	80	1	10
10:00 am	1	10	1	20	60	90
...						
05:00 pm	20	30	60	80	1	10
11:30 pm	0	10	80	100	0	10

The above-mentioned constraints have been used for the generation of so-called candidate designs in the following step. In this respect, a candidate design is generated with a randomized Dirichlet routine. The latter yields three random numbers, whose sum equals one and every number describes the percentage of a particular persona. Initially, 5,000 candidate designs are generated, while each of the latter represents a unique course of population compositions throughout the day. In the next step, it is checked if the candidates comply with the above-defined constraints. The routine is completed if 50 candidate designs are found, which are compliant for the entire daytime. The achieved variability in terms of population composition is illustrated in Figure 4.

The variable compositions introduced above have to be conjunct with a certain assumption about the overall passenger load in the next step. The latter could potentially be prescribed by a fixed population size whereas only the composition is varied. However, in the special application of a subway station, we know that there are certain relationships between population size and composition. In this respect, a literature review revealed some basic findings about the average course of the passenger load throughout a day. Regarding the latter, Weidmann (Weidmann, 1994) observed a double peak structure when summarizing multiple German studies. He furthermore concluded that approximately 12% of the daily passenger load occurs during the peak hour in the morning. For demonstration purposes, the daily course of the relative passenger load applicable for Hamburg has been utilized as shown in Figure 4.

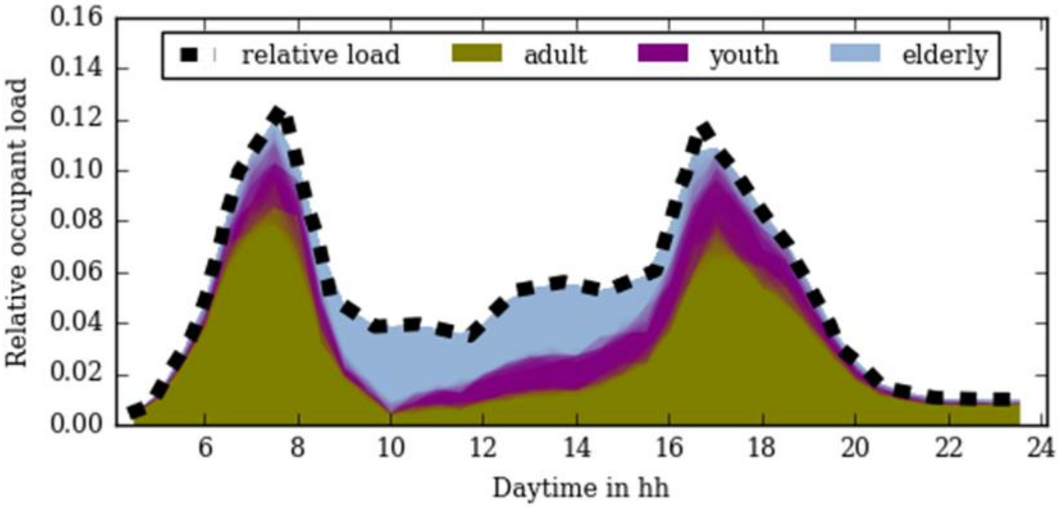

Figure 4. Daily Course of Relative Passenger Load Constituted by Variable Populations

Since the passenger load is resolved in half hour steps, the 50 candidate designs consist of 50 x 40 = 2,000 different constellations, which cannot be entirely incorporated into the simulation. Thus, a k-means clustering has been applied to the candidate designs in order to derive 100 population clusters. The identification of these clusters has been optimized with special emphasis on variability and passenger load. The general purpose of these clusters is to aggregate similar candidate designs (e.g. early morning and late night) and focus the computation on highly variable sub-domains (e.g. the peaks).

In order to specify the total population size, the proposed workflow has been conjunct with the current traffic data applicable for the investigated station. In this respect, approximately 90,000 passengers use both subway lines serving the station (City of Berlin, 2014). In order to account for both the assumed daily course and increasing passenger numbers, the total passenger number has been increased by a surcharge of 20% yielding 108,000 passengers per day. The latter number represents the integral surface below the curve describing the daily percentage load. In turn, the peak hour yields approximately 13,000 passengers. Regarding one particular event within this period, three served tracks and twelve arrivals per hour result in 375 passengers per train. Moreover, additional 30% have been assumed on the platforms. This assumption is based on a technical guideline applicable in Germany (TRStrab BS, 2016) and is in good accordance with the findings of field studies conducted in the station (Hofinger et al., 2016). It is noteworthy that these numbers represent the maximum load. In case of population clusters representing less frequented daytimes, the latter are reduced accordingly.

With regards to the final design of experiment, the introduced population clusters serve as the single system parameter in this study. Additional parameters (e.g. detection time, alarm time) may be incorporated for a more comprehensive analysis. However, in this case, we will introduce no further variations. The generated population clusters yield 100 occupant scenarios, whereas each of them is computed with 15 realizations.

Results

Without doubt, there are many other relevant observables when analyzing pedestrian dynamics. However, in the frame of this study, the impact of heterogeneity and temporal dynamics will be investigated based upon the required safe evacuation time (RSET). For each scenario, the latter is calculated as the 95th percentile out of all realizations. In this respect, Figure 5 provides the correlation between the occupant numbers, which are induced by the particular population clusters and the resulting evacuation times.

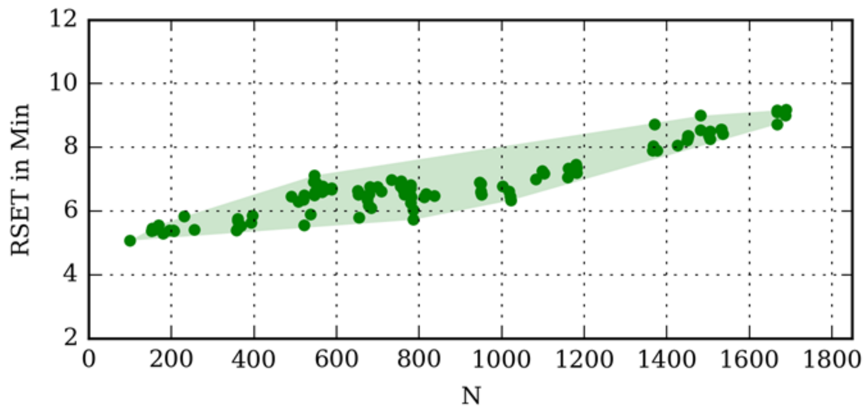

Figure 5. Relationship between Occupant Number and Required Safe Evacuation Time

As expected, increasing occupant numbers yield higher evacuation times. However, the results show remarkable fluctuations; especially in the range from approximately 500 to 800 occupants. This range represents the passenger loads that occur in the off-peak hours, which are rather variable in terms of population composition. Interestingly, these fluctuations yield a certain plateau of RSET, which potentially can result in similar evacuation times despite variable occupant numbers in a range from 500 to 1,100 occupants. Moreover, occupant numbers greater that 1,000 appear to yield less scattered results. On the one hand, this finding may correspond to the fewer sampling points. On the other hand, it is also related to jamming, whose occurrence then establishes as the system's main determinant.

Persona method may be generally applied to simulations for evacuation. These situations are likely to cause stress (e.g. due to a perceived danger) in users of an infrastructure which has an impact on the individually perceived options to act and in consequence on human behavior. Applying Persona method has the potential to fully account for this behavioral and emotional characteristics and motivation of people in evacuation scenarios, thereby creating more human-like agents for pedestrian simulation. Persona method at the same time can be applied to different kinds of scenarios: Specific evacuation scenarios that are likely to occur are evacuations initiated by a (false) alarm. In these situations the users of an infrastructure may not perceive an immediate threat to their lives or personal well-being. If fire and smoke are the cause for an evacuation, the kind and density of smoke may influence the reaction time as well as the walking speed.

CONCLUSION

Human factors offer a wide range of psychological models to describe human beings in interaction within different settings and scenarios. Compared to this variety, pedestrian models do not yet include the same range of individual parameters, neither on a tactical nor operational or strategic level.

In order to integrate more human-like agents for pedestrian simulation and to sample representative populations, the Persona method could serve as a striving force to focus on further individual human factors aspects. Successfully integrating the relevant characteristics and subgroups of users of an infrastructure as personas allows assessing realistic behavior, e.g. of passengers displayed during evacuation or when given information by an organization or agency. Decision makers can use this approach to prepare for crisis or disaster management.

In this paper Personas were selected to represent subgroups of the populations inside a German subway station. Not only the variation in the proportions of these subgroups was taken into account for pedestrian simulation but also their respective psychological and physiological characteristics were combined to form different personas.

The results of the case study gave proof that it makes a difference to include personas into evacuation simulations, as displayed by means of the required safe evacuation time (RSET). Regardless of this effect, further research is necessary. Additional personas could be defined and implemented, representing subgroups of the overall (subway-user) population, e.g. subway staff with guidance authority.

Applying Persona method to evacuation simulation revealed both benefits and shortcomings. For the presented product: Evacuation design in subway systems, the Persona method offered a useful approach for selecting individual human aspects for modelling pedestrians and to improve objectivity in the specification of different user types. However, the implementation of personas for this novel context of pedestrian simulation was limited and required the definition of an additional step 8 to the Persona method proposed by Cooper (2007). This step 8 was added by the authors and specification of categories of the Persona method was necessary. The Persona method may impose further restrictions for use in domains other than software designs. It may be vague with respect to the identification of relevant "target-user" parameters (e.g.: Does it matter if the user wears a striped jacket?). Overall, applying Persona method still appears a promising approach potentially improving occupant scenarios and the sampling of representative population for pedestrian simulation.

RSET was the initial performance measure of the case study, in order to highlight the effects of integrating additional human characteristics (here by implementing Persona method). However additional processes during an evacuation are equally important, e.g. acts of helping behavior or seeking information, which could point to necessary changes in the design of the infrastructure, in return fostering safe, smooth and quick evacuation. In order to investigate effects of different evacuation scenarios (e.g. evacuation initiated by fire or explosions) and of different types of infrastructures (below or above ground), psychological human factors aspects defined for personas (e.g. cognition, emotions, motivation in the variables presented above) need to be included into pedestrian simulations in more detail. When transferring personas into a machine-readable format, an ontology using a web ontology language (OWL) would potentially capture the full semantic richness of the personas. This richness could then be used for implementing more exhaustive personas into pedestrian simulations. At the same time pedestrian simulation, e.g. the framework of JuPedSim used by the authors, should be extended to integrate additional personas´ characteristics apart from mainly physical variables. Whether or not, it is worth the effort of including personas (e.g. for a sub-population) or an additional variable of a persona (e.g. route choice strategies other than shortest path) in evacuation simulation depends on the objective of using a pedestrian simulation. One objective in the case study described is to prepare organizations for guiding users of an infrastructure along escape routes smoothly. Depending on the initial scenario for disaster management, further psychological mechanisms might have to be taken into account while others may turn out irrelevant for creating and implementing novel personas for simulation purposes.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Berlin Transportation Service (BVG). This research is partly funded by the German Ministry for Education and Research (BMBF) contract No. 13N13266 (project ORPHEUS).

The authors gratefully acknowledge the computing time granted on the supercomputer JURECA at Jülich Supercomputing Centre (JSC).

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People Behaviors in Crisis Situations: Three Modeling Propositions

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ABSTRACT

Warnings can help to prevent damages and harm if they are issued timely and provide information that help responders and population to adequately prepare for the disaster to come. Today, there are many indicator and sensor systems that are designed to reduce disaster risks. These systems have proved to be effective. Unfortunately, as all systems including human beings, a part of unpredictable remains. Indeed, each person behaves differently when a problem arises.

In this paper, we focus on people behaviors in crisis situations: from the definition of factors that impact human behavior to the integration of these behaviors, with three different modeling propositions, into a warning system in order to have more and more efficient crisis management systems.

Keywords

Behaviors, modeling, crisis management, data analysis

INTRODUCTION

Context

The inclusion of cognition and realistic human behavior to reproduce or predict some events or actions is a common concern for intelligent systems developers. Understanding human behavior in a manner that it could be integrated in intelligent systems is still a challenge that needs the interconnection of heterogeneous elements such as physiology, personality, social or environmental items.

Today, thanks to the Information and Communication Technologies (ICT), it is faster and faster and more efficient to manage real time data, make maps from geolocalised data or make assessments based on scenarios that integrate data from different sources. These improvements permit to crisis management systems, developed to face disasters that can be humanitarian, economic, ecologic or social for example to become more and more complex. These crisis management systems help to predict as precisely and as soon as possible the crisis consequences and it evolution on a given territory. Despite knowledge and technologies developed in order to minimize or avoid disastrous consequences that can produce crises, they remain, by definition, determined by aleatory phenomena which all components are not always considered in these crisis management systems: vulnerability of territories, coordination measures between services, or the probable behaviors of populations in danger for example, are sometimes neglected.

Objectives of the study

Before and after a crisis, people act according to their own knowledge and interpretation schemes (Mileti and Sorensen 1990), these schemes do not always permit people to react in an appropriate way to risk situations and can lead to dangerous reactions. To respond to these problems, crisis management systems include, most of time, warning systems that permit to (i) know risk and define indicators to be monitored to anticipate crisis, (ii) monitor these indicators in order to be able to (iii) trigger warnings and broadcast them as fast as possible to people in risk situations, and finally (iv) bring up and raise awareness among populations exposed to risks. ICT are a key element in these warning systems, they permit to orient people behaviors when a crisis is announced by giving them information before the crisis, and orienting them in the perceived signals interpretation during the crisis. The potential influence of communication is sometimes under-exploited, warnings are for example often simplified and reduced to "Red Alerts" instead of giving concrete advice and recommendations to populations (Comes et al. 2015).

The consideration of laws and phenomena that influence human behaviors in crisis situations seems for us an important area of research and reflection on the improvement of warning broadcast, crisis communication, and on the development of politics of education and of targeted awareness. In this article, we endehavour to understand how and according to what factors people react and adapt their behaviors in crisis situations. To do so, we propose to start with a first analysis of the factors that determine people behaviors in crisis situations in order to face environment changes and to react to information and warnings that they receive (Arru and Negre 2017). Then, we propose three modeling solutions to represent these factors that can be computed in order to validate research hypotheses from data issued of simulations or pasts crisis situations.

Thus in a first time, to lead this study, we expose our definition of the behavior concept with a state of the art, we precise in this part the stakes of behavior in crisis situations and the most commonly observed human reactions. Afterwards we present the list of factors that we identified to have an influence on behaviors, with a list of indicators associated to each of them. In a third time we propose our three choices of modeling to integrate these factors and their indicators in a computational representation. We discuss in this third section the advantages and inconveniences of each representation and of their capacities to both represent the reality and to validate efficiently researches hypotheses. Finally we present research perspectives that we would like to pursue in future work to apply our modelings on concrete cases.

WHAT IS BEHAVIOR ?

General definition

The behavior concept needs to be precised and well defined, it can be approached very differently in the scientific sphere. Some speak of "nomadic" concept that can take several meanings according to the disciplines (Toniolo 2009). In philosophy, for example, definitions rest on conscience and experiences notions (Merleau-Ponty 1942), although in cognitive sciences it can be aborded as a logical suite of actions (Skinner 2005). The most important number of works on the subject is provided by human sciences, notably in ethiology and in psychology domains (Alcock 1989; Cooper et al. 2007). We take over in this paper the definition of Sillamy (1983) for whom behavior corresponds to the "reactions of a person, considered in a milieu and in a given time unit to an excitation or a set of stimulation".

We propose here an approach based on cognitive and environmental factors that can be modeled in a computable way. Several models already exist in the computer science literature, in MAS (Multi-Agent Systems). We can cite the one for example of Müller and Pischel (2011) with the inteRRaP architecture, or the one of Ferguson (1992) with his TouringMaching architecture that represents a particular functioning of human behavior in precised situations. This kind of representations takes into account only in a weak extent individual interactions (Goldstone and Janssen 2005), and in crisis situations they are generally targeted on a few actions that have been already defined (Zoumpoulaki et al. 2010; Adam et al. 2010).

Human behavior is also integrated in artificial intelligence researches whose idea is to transport in a virtual reality knowledge elements and the treatment of theses elements that make possible for virtual agents to make strategic choices. We find this kind of researches in domains such as automatic production of explanations or in mathematical problems resolution (Balacheff 1994), but it is still difficult on this day to integrate cognitive dimensions of behaviors to these computer science representations.

Behaviors in crisis situations

Individual behaviors in crisis situations do not correspond to everyday life behaviors. It is difficult to represent these behaviors from the information that have been obtained after a crisis as this information is always static, punctual and contextual, and it make it difficult to integrate the whole diversity of human reactions that can appear in crisis situations. We can however work to establish tendencies, or rules that permit to determine factors that orient particular behaviors. The behaviors frequently observed in crisis situation are the followed (Dauphiné and Provitolo 2013): evacuation, escape; panic escape; stupor; sideration; immobility; confinement; sheltering; struggle again disaster effects; assistance; urgency assistance; "antisocial" behavior; curiosity; return on the habitation or work place. We distinguish three types of behaviors : (i) reflex or instinctive behaviors that permit a fast action by struggle, astonishment or evasion, (ii) panic behaviors, or crowd phenomena that can emerge from imitation or contagion mechanisms and (iii) controlled behaviors that are reasoned (Provitolo et al. 2015).

It is important to take into account a maximum of elements to study crisis behaviors, two events that seems similar can bring about very different reactions. Between the tsunami that occurred in Fukushima the 11 March of 2011 and the other that occurred five years after, the 22 of November 2016, authorities and inhabitants reactions have significantly evolved. In 2016, The Prime Minister ordained to the government to give to people a precise and reliable information on the evacuation ways and means and the appeals to evacuate have been more much numerous, reactions have been generally strongly influenced by the experience lived five years earlier.

Emotions such as fear or surprise can also have a strong influence on crowd movements as in the Nice attacks the 14 of July of 2016, which was a National Day in France. After the attacks, some people began to run without knowing where to go, several rumors have been spread in streets... These panic movements are very relied to danger perception and to the perception of the means that people have to escape; they also can worsen crisis consequences.

Behavioral factors role

A crisis approach from the analysis of behaviors is relatively complex and needs a good understanding of the mechanisms underlying collective movements. Behavior mechanisms in crisis situations are still not much studied (Helbing et al. 2000; Provitolo et al. 2015) or poorly represented (Quarantelli 2008), notably in computer sciences. They are often limited to the observation and analysis of reactions produced during a specific event (Ripley 2009; Ruin 2010), from data collected or from a precise behavior analysis such as pillaging or panic (Quarantelli 2008; Hagenauer et al. 2011; Crocq 2013). We take an interest here to individuals behaviors without including the complexity of interactions between individuals in a first time, and considering the collective as a separate entity with its own mechanisms. A distant objective of this study is to be able to propose thereafter an approach of the collective movements in crisis situations.

BEHAVIOR IMPACT FACTORS

Before to be able to propose a computer science model and to analyze the influence of the different behavioral factors on the global reactions of populations in crisis situations, we have to describe individuals behaviors by decomposing as much as possible their factors. Bases components are indicators, measurable elements that can be aggregated with different methods to describe a multitude of observations on a same parameter.

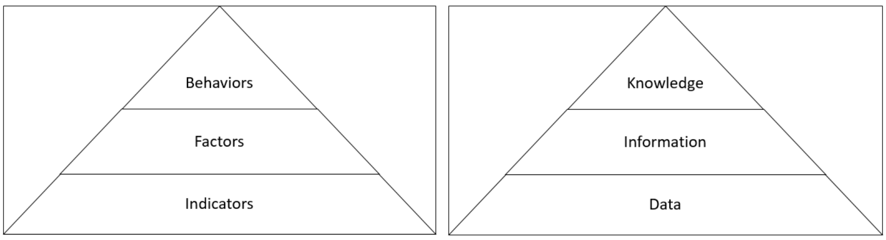

Figure 1. From indicators to behaviors: overview

Figure 1 represents the indicators, or data, that are the components of the behavioral factors, and the base of a structure that leads to behaviors, knowledge, understanding. An application example of this kind of structure has been proposed to rank Smart Cities (Giffinger and Pichler-Milanović 2007), it permits to describe the smart level of cities from different factors. Indicators for example of sanitary condition in this representation are life expectancy, number of hospital beds, the number of doctors per inhabitant and the satisfaction level on the health system quality.

Proposition of twenty factors

We choose here to take the behavior formalization of Kurt Lewin (1936), who conceptualize the behavior B in function of the person P and it environment E: B = f (P,E). The twenty behavioral factors that we identified have been selected to have an influence on human behaviors in crisis situations from researches in literature. We assemble them in two categories according to the objects they refer to, individual and environmental, and to the type of information sources that allows to characterize them. They are presented here with the list of indicators associated to each of them.

Factors linked to the individual

1. Civil status : age (F1a), sex (F1b), nationality (F1c), residence place (F1d), level of schooling (F1e), occupation (F1f).
2. Personality : desires (F2a), moral principles (F2b), sociability (F2c), beliefs, religious or not (F2d), capacity to take decisions (F2e), mimetic reactivity (F2f).
3. Motivation to escape/defend (F3) : motivations are strongly influenced by the experience, risk assessment, the current action and the physiological signals identified after.
4. Responsibility (F4) : in the situation when a fire alert is given in a school for example, a teacher can have a reaction absolutely different depending on whether he is alone in his office or he is in a classroom, teaching to a student group. He can have no reaction if he is alone, but he will be much well disposed to evacuate with its students in good conditions if he is responsible of them and has to be an example.
5. Emotions : joy (F5a), sadness (F5b), anger (F5c), disgust (F5d), fear (F5e), surprise (F5f), contempt (F5g).
6. Experience : crisis faced in the past (F6a), objective escape/defend ability (F6b), subjective escape/defend ability (F6c).
7. Explicit knowledge : general knowledge shared by the population (F7a), training followed (F7b), access to documents (F7c), access to knowledge sharing tools (F7d) (Arru, Negre, et al. 2016).
8. Risk assessment : objective assessment (F8a), subjective assessment (F8b).
9. Perception of the alert system (F9) : we define perception as the process of collecting, organizing, and interpreting stimuli that can be information or knowledge coming from different sources (Arru, Mayag, et al. 2016).
10. Current action : interaction (F10a), concentration (F10b) and movement (F10c) needed.
11. Physiological signals : hearth rate (F11a), tightness (F11b), transpiration level (F11c), muscular tension (F11d).

Factors linked to the environment

12. Geographic zone characteristics (Comes et al. 2015) : zone extent (F12a), population density (F12b), poverty level (F12c), economic status (F12d), urban level (F12e), population pyramid (F12f), cultural characteristics : individual versus group orientation (F12g), trust in government (F12h).
13. Interaction and mobility capacity : frequented area (F13a), smartphone (F13b), access to transportation (F13c).
14. Perceptible signals of the crisis : indicators of perceptible signals depend directly of the concerned crisis type, this is why we defined three generic indicators, visual signals (F14a), sound signals (F14b), olfactory signals (F14c).
15. Period characteristics : day/night (F15a), number of hours from the crisis peak (F15b).
16. Temporal phase of the crisis : before (F16a), at the beginning (F16b), at the peak (F16c), on the decreasing phase (F16d), after (F16e) the crisis.
17. Alerts / Transmitted information : quantity (F17a) and quality (F17b) of information transmitted, number of diffusion channel (F17c) (DGSCGC 2013).
18. Entourage characteristics : density of population (F18a), presence of authority representatives (F18b), security level of the area (F18c), presence of close relations (F18d) (Dupuy 2003).
19. Behaviors of the closer people : contagion level of the three dominant behaviors (F19a), (F19b), (F19c). The contagion level of an agent vary according to the number of neighbourhoods who have a similar activity (Granovetter 1978) (Solomon et al. 2000).
20. Entourage global behavior (F20) : global behavior followed in an extended perimeter (Dupuy 2003).

Figure 2 sums up data, indicators F1a, F1b... that indirectly characterize behaviors.

KNOWLEDGE	INFORMATION		DATA							
Behaviors	Factors linked to individual	Civil status	F1a	F1b	F1c	F1d	F1e	F1f		
		Personality	F2a	F2b	F2c	F2d	F2e	F2f		
		Motivation to escape/defend	F3							
		Responsability	F4							
		Emotions	F5a	F5b	F5c	F5d	F5e	F5f	F5g	
		Experience	F6a	F6b	F6c					
		Explicit knowledge	F7a	F7b	F7c	F7d				
		Risk assessment	F8a	F8b						
		Perception of the alert system	F9							
		Current action	F10a	F10b	F10c					
		Physiological signals	F11a	F11b	F11c	F11d				
	Factors linked to the environment	Geographic zone characteristics	F12a	F12b	F12c	F12d	F12e	F12f	F12g	F12h
		Interaction capacity	F13a	F13b	F13c					
		Perceptible signals of the crisis	F14a	F14b	F14c					
		Period characteristics	F15a	F15b						
		Temporal phase of the crisis	F16a	F16b	F16c	F16d	F16e			
		Alerts / Transmitted information	F17a	F17b	F17c					
		Entourage characteristics	F18a	F18b	F18c	F18d				
		Behaviors of the closer people	F19a	F19b	F19c					
		Entourage global behavior	F20							

Figure 2. From indicators to behaviors: detailed vision

MODELING

One of the reasons that lead us to propose a model integrating our factors is to give the possibility to researchers to take into account human reactions in crisis situations. With a model of behavior we can test hypotheses on the participation of the different factors to crisis behaviors for a given population. We can also distinguish the importance of the different factors implied for different types of crisis. The results obtained from such analyses could help prevention and preparation in crisis managing programs and help to bring models that provide real time predictions with the integration of new indicators to the monitoring step. Unfortunately these steps need validated models with large data sources that we will not be available in medium term. A combination of different models seems necessary for us to both have a representation of the definitions and interaction complexity, and to be able to aggregate data to offer a synthetic vision of validated hypotheses. A lot of approaches already propose combinations of several models (Ding et al. 2006; Swat et al. 2016; Lin and Lee 1991).

To describe our three propositions of models we take the illustrative example of a fire occurrence in a University. We focus on a population of 20 professors, four of them are in a classroom and the other are working in their offices. Four factors are considered : (i) civil status, (ii) responsibility, (iii) perception of the alert system and (iv) perceptible signals of the crisis and one behavior. Then, we retain the following indicators and the evacuation behavior :

- age (F1a), with three levels : from 0 to 30, from 30 to 50, from 50 to more ;
- occupation (F1f), with two levels : student, professor ;
- responsibility (F4), with two levels : yes, no ;
- perception of the alert system (F9), with five levels : 1, 2, 3, 4, 5 (1 referring to a strong unsafety and 5 highlighting a strong safety perception) ;
- visual signals (F14a), with two levels : yes, no ;
- sound signals (F14b), with two levels : yes, no ;
- olfactory signals (F14c), with two levels : yes, no ;
- evacuation, with two levels : yes, no.

1 - Entity–relationship model with a statistical approach

The entity-relationship model can be directly extracted from the indicators presented in the Figure 2, with the addition of relations between the different variables. According to the perspective of analysis preliminary chosen, we can select indicators and relations to test. The MCA (Multiple Correspondence Analysis) method is particularity adapted in this approach, allowing to test hypothesis from link analysis between any number of variables. It is particularly adapted to survey analysis.

Data for this models are represented as a file with twenty lines, corresponding to the number of individuals, and 8 columns, corresponding to the number of indicators. The first line of the file will be for example 0 1 1 3 0 0 1 1, referring to a professor between 0 to 30 years old, with no responsibility, a score of 4/5 for his perception of the alert system and who perceive visual and sound crisis signals but no olfactory signals, and who do not evacuate. Levels of each qualitative variable are coded as numerical values. The first result from our data file is the variable representation table that we can observe on Figure 3, constructed with the FactoMineR package integrated in R free software environment [1]. We can observe on this Figure that the variable "age" is linked to both first and second dimensions, "visual signals" is much linked to the second dimension and "evacuation" and "responsibility" to the first dimension. We cannot say much more from this Figure and need a representation of categories to interpret these relationships. We use the MCA factor map on Figure 3 to view that the second dimension opposes "no sound signals" and "no evacuation" between "responsibility" and "evacuation".

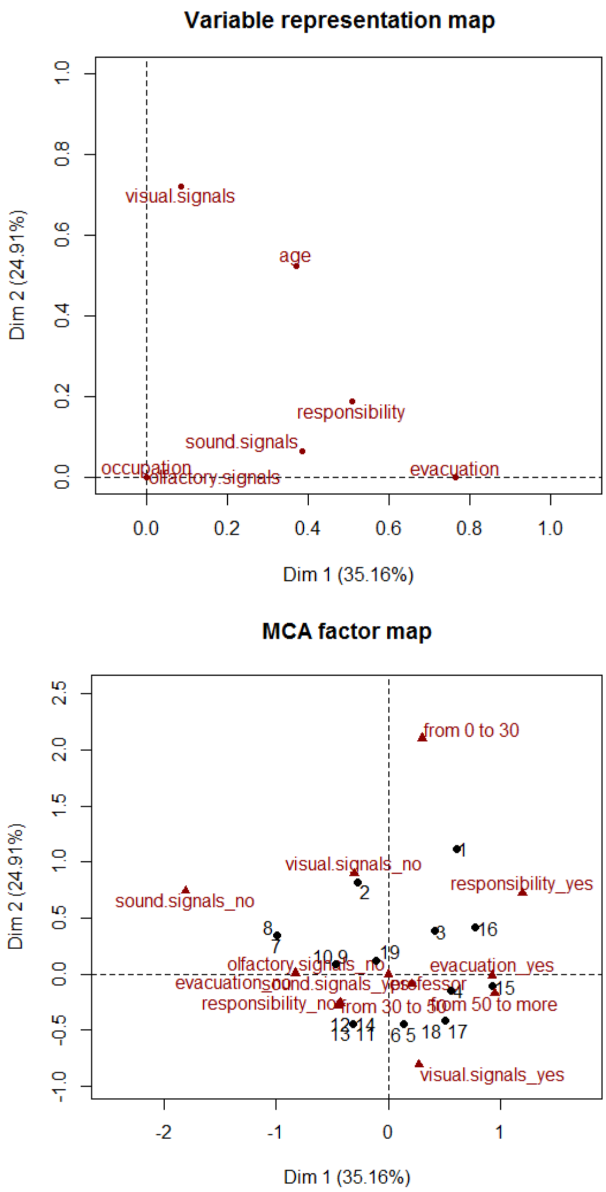

Figure 3. Variable representation map & MCA factor map

We can enter in detail of the factors contributions with the analyze of coordinates, contribution, cos2 (quality of representation in [0;1]) and the v.test value, generally comprised between 2 and -2. For a given variable category, if

[1] https://www.r-project.org/ & http://factominer.free.fr/index.html

the absolute value of the v.test is superior to 2, this means that the coordinate is significantly different from 0, see Figure 4.

Categories (the 10 first)

	Dim.1	ctr	cos2	v.test	Dim.2	ctr	cos2	v.test
from 0 to 30	0.304	0.461	0.011	0.442	2.102	31.130	0.520	3.059
from 30 to 50	-0.444	5.911	0.338	-2.468	-0.279	3.296	0.134	-1.551
from 50 to more	0.945	11.136	0.319	2.396	-0.171	0.513	0.010	-0.433
professor	0.000	0.000	NaN	NaN	0.000	0.000	Inf	-Inf
responsibility_no	-0.426	6.331	0.507	-3.022	-0.258	3.292	0.187	-1.835
responsibility_yes	1.192	17.726	0.507	3.022	0.724	9.218	0.187	1.835
visual.signals_no	-0.305	2.082	0.083	-1.226	0.895	25.381	0.721	3.602
visual.signals_yes	0.274	1.874	0.083	1.226	-0.805	22.843	0.721	-3.602
sound.signals_no	-1.807	16.288	0.384	-2.629	0.741	3.866	0.065	1.078
sound.signals_yes	0.213	1.916	0.384	2.629	-0.087	0.455	0.065	-1.078

Figure 4. Contribution of the variable categories on the dimensions 1 and 2

In practice, we can use this method to explain one variable from the others, but we can't define preliminary relations between indicators. Indeed known relations between indicators represent information that have to be taken into account.

2 - Ontology and decision rules

Ontologies have already been proposed to represent behavioral strategies (Silverman 2001; Silverman et al. 2006). We can integrate our behavioral factors on ontologies implementations, with a working memory module that could take advantage of decision rules to discover information from data obtained. In Figure 5 we can see the ontology of the illustrative example model, constructed with Protege [2].

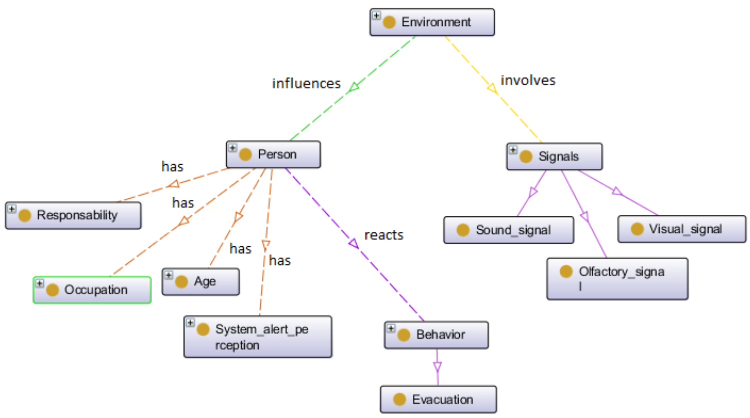

Figure 5. Ontology example applied to the illustrative example

In computer science, an ontology is an « explicit formal specifications of the terms in the domain and relations among them » (Gruber 1993). Coming from Knowledge engineering, it makes possible to represent semantic relations and composition or inheritance. Its objective is to be consensual, normative, coherent, shareable and reusable. It provides a formal semantic of the information allowing its use by a computer. Here, our ontology describes relationships such as "influences", "involves"... which allow to identify the precise nature of the links between the concepts (behavioral factors).

3 - Predictive models and correlation analysis

With a complete information on past situations or statistical studies we could construct Bayesian Networks for example, or Markov Decision Process models to make predictions from the existing data in crisis management systems. Today we do not have this possibility, we propose in Figure 6 a Bayesian network constructed from hypothetical probability tables.

[2]http://protege.stanford.edu/

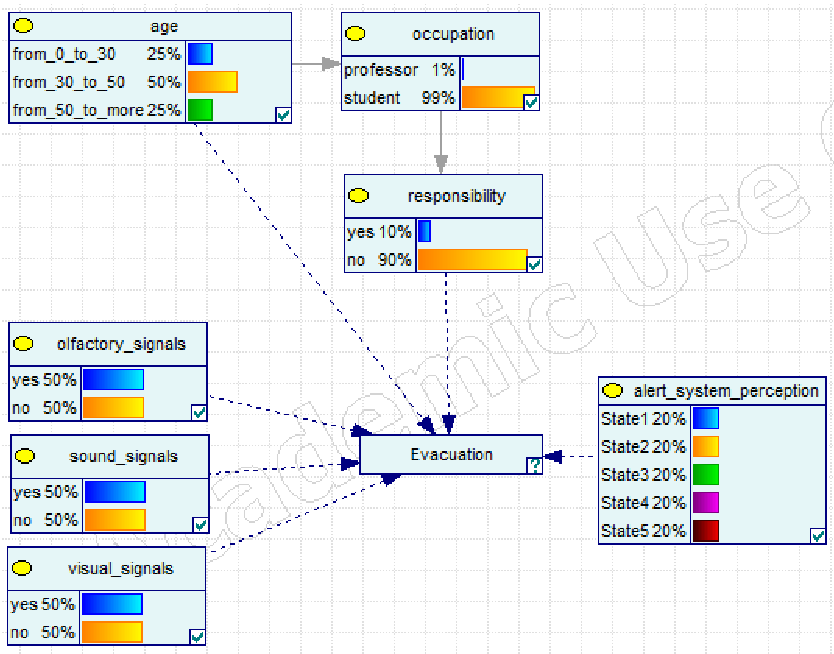

Figure 6. Bayesian network representation of the illustrative example

We suppose that the age of a person have an influence on his occupation and that his occupation influence his responsibility level. The age will also weigh directly on the decision to evacuate, but the occupation in this example only have an indirect influence on this decision to evacuate via the responsibility node.

A Bayesian network is, in computer science and statistics, a probabilistic graphic model representing random variables in the form of an acyclic oriented graph. Bayesian networks are both (i) models of knowledge representation, (ii) conditional probability calculators, and (iii) a basis for decision support. Here, we can describe the causal relationships between variables by this graph (Figure 6). The causal relationships between the variables are not deterministic but probabilistic. Thus, the observation of a cause does not systematically entail the effect(s) that depend on it, but modifies the probability of observing them. The interest of Bayesian networks is to take into account simultaneously of a priori knowledge (in the graph) and of the experience contained in the data.

Discussion

Our modelings choices have to be refined to enrich a representation at least partly probabilistic, or resting on fuzzy methods that are the two bases to reason and take decisions on uncertain situations (Gaines 1978). Indeed, "behavior is not reducible to a state or a set of points that would define the trajectory of a mapped out driving. It contains uncertainety." (Toniolo 2009).

The proposition of three models to represent people behaviors in crisis situations remains the theoretical part of our research project. Obviously, they will be put to the test with probably a reassessment of the models, and a need for more detailed representations to be able to interpret the results.

It should be noted that, at first glance, a combination of these three models, combining knowledge, expertise, experience and probability / statistical engineering, could be envisaged, making it possible to benefit from each one, thus obtaining the most complete and as realistic as possible behavior modeling.

CONCLUSION AND PERSPECTIVES

In this article, we proposed the first step to integrate a global vision of people behaviors in crisis situations in crisis management systems. We identify twenty behavioral factors that we split up in indicators in order to make computable elements to integrate to our propositions of models.

In a first time, we plan to collect data in simulations to work on a part of the indicators of our model. We choose to work first with the entity–relationship model with a statistical approach to test hypothesis based on responsibility and physiological signals co-factors. The analyze will be based on responses from a survey with multiple choice questions proposed to participants on their civil status, experience, the context and their actions during the simulation, and their personality. In a second time, we would like to test the ontology and decision rules model with the integration of relations. And in the longer term, we hope to tend towards the modeling of collective behavior in a crisis situation.

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Extraction of significant scenarios for earthquake damage estimation using sparse modeling

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ABSTRACT

The recent diversification and accumulation of data from GPS equipped mobile phones, building sensors, and other resources in Japan has caused a large increase in the number of earthquake disaster scenarios that can be identified. Disaster prevention planning requires us to contemplate which scenario should be focused on and the required response to various scenarios. As a means to solve this problem, the damage distribution of building collapse and fire from GPS data can be used to estimate future damage based on people flow and various hypocenter models of earthquakes. We propose a method that uses sparse modeling to extract scenarios that are important for disaster estimation and prevention. As a result, this paper makes it possible to quickly grasp the scenario distribution, which was previously impossible to do, and to extract the significant scenarios.

Keywords

Big data, Mobile phone GPS logs, People flow, Micro geodata, Damage distribution

INTRODUCTION

The 2011 East Japan great earthquake and the 2016 Kumamoto earthquake caused serious damage that could not be predicted by conventional science and technology. Since Japan has experienced major earthquakes in recent years, another major earthquake, such as a Nankai Trough earthquake, is expected to occur. Reducing earthquake damage is an important national and societal issue. To address this problem, High Performance Computing (HPC) simulation technology such as General-Purpose computing on Graphics Processing Units (GPGPUs) and an improved understanding of the circumstances and technology for estimating earthquake damage in various and highly precise ways are being developed.

Big data collected from mobile phone GPS logs can reveal the movement of people and improved observation techniques using building sensors can show the attributes of each building and of each residential or office unit contained within. This information is referred to as "micro geodata" (Akiyama et al., 2013). Micro geodata includes various types of micro spatial data such as digital maps and digital phone books that allow us to observe the distribution of people and building in Japan. Micro geodata can be useful in various fields such as urban planning, disaster response, marketing, human behavior analysis, and so on. In disaster planning, the types of structures, their fire resistance performance, the age of each building, and the precise population distribution at each time frame in large areas are expected to be useful for precise and high accuracy estimation of earthquake damage. The maintenance of such micro geodata makes it possible to estimate damage in a given building or unit.

At present, the government of Japan estimates the collapse, fire, and tsunami damage risk of earthquakes separately for a few scenarios by prefecture or using 500m grid-cell units at a minimum (Central Disaster

Prevention Council, 2012). Although human damage is estimated for each damage event, the events and related damage are not independent; therefore, it is necessary to develop a method for integrated damage estimation of collapse and fire by earthquakes. Concerning the resulting human damage, it is impossible to predict what time and day an earthquake will occur. The damage also depends greatly on the flow of people. Therefore, we have to perform simulations for various scenarios. For example, if people are gathering at some event, such as a festival, the number of people affected by the earthquake will increase. Thus, it is not enough to only simulate a single average scenario. The simulation of various scenarios based on micro geodata can provide a quantitative indication of the range of potential damage, which cannot be done by current damage assessment techniques.

While the circumstances and technology for estimating earthquake and tsunami damage in various and more precise ways are being developed, the diversification and accumulation of new data is causing a large increase in the number of disaster scenarios to be considered. This brings about two problems. First, when considering disaster prevention, for example during regional disaster prevention planning, which scenarios to focus on and how to respond to those scenarios should be considered. This poses a "scenario selection problem". Secondly, since high-precision damage estimation models such as Multi Agent Simulation (MAS) and numerical response analysis of buildings require huge computational resources, there is a need to narrow down the scenarios to be calculated beforehand. If we can further analyze the results and narrow down the scenarios, we can extract scenarios that are scientifically important (e.g. disaster occurrence date/time and ground motion).

This study is possible to select significant scenarios on scientific grounds rather than choosing by heuristics, e.g. choosing to estimate the damage at 6 P.M. in winter. In addition, we are analyzing damage in each region by considering the regional characteristics and are able to show the damage modes and tasks for each region. By developing a damage estimation and evaluation environment based on micro geodata, we can apply advanced damage estimation models such as MAS only for significant scenarios and therefore the damage simulation will be developed more efficiently

Previous work on design integrated damage estimation of earthquakes

Although we have found no previous research for estimating the collective damage from building collapses, fire, and tsunamis caused by earthquakes, some previous research has been performed on integrated simulation of the damage caused by collapse and tsunamis excluding fire in building units. Wijerathne et al. (2012) developed an integrated earthquake simulator for centralized management of earthquake ground motion prediction, tsunami prediction, building damage prediction, and evacuation simulation. The simulator uses the integrated earthquake simulator (IES) developed at the University of Tokyo Earthquake Research Center and performs the calculations using the supercomputer "Kei". Ichimura et al. (2014) developed a structural response analysis for the simulation of building collapse in Takamatsu City, Kagawa Prefecture, Japan by inputting the seismic waves observed in past earthquakes. In addition, they constructed an assumed urban model and applied a tsunami evacuation simulation with 200,000 agents. However, they suggested that it is difficult to extend and apply this research in another city unless the building data is supplied as a micro geodata. For such a highly accurate simulation, the building data and the population distribution data from micro geodata are indispensable. In Japan, often municipalities own the attribute data of buildings and the data are not public. In addition, people distribution data can be improved by using the large-scale GPS data of mobile phones, however this option is still under-utilized. In other words, in order to obtain complete population distribution data for micro simulation of MAS, etc., it is necessary to further prepare high-definition input data by using obtained micro geodata.

As a means to solve this problem, we will develop high-definition base data for building units and individuals based on actual people flows derived from GPS data from mobile phones and building distributions that actually occurred in the past using by detailed geodata such as micro geodata. In addition, we develop a platform that can estimate the integrated damage of collapse and fire in various scenarios and apply a detailed estimation method. The novelty of this research is creating and analyzing the damage distribution from various scenarios, estimating the significant damage in each region, and extracting the significant scenarios for each region.

Objective

The objectives of this research are as follows:

1) Establish an environment that can estimate the collective damage caused by collapse and fire in detail.

Estimate human and physical damage by integrating collapse and fire events on each building or person basis. We suppose that the physical damage and casualties are due to building collapse and fire-spread. The scenarios are simulated in 15-minute units. Around 10,000 scenarios as enormous numbers by collapse and fire. By using micro geodata, a non-aggregate analysis of the building unit or person units is established, so our damage estimation environment can apply advanced damage estimation models such as MAS or numerical response analysis for the building collapse.

2) Damage evaluation: we analyze the estimation results to identify important damage and scenarios for each region.

We calculate the risk distribution from various scenarios estimated by (1). We also calculate the likelihood of each scenario to obtain the damage distribution for each region (250 m grid), and estimate the amount of significant damage (maximum damage amount, the maximum likely damage amount above average, and the maximum likely damage amount). Finally, by using the Lasso approach to sparse modeling, we extract the scenarios that explain the important damage amount obtained for each region.

METHOD

Figure 1 shows the process flow of our method. To evaluate damage for each building, we use residential maps (2008-2009) and Telepoint Data (2008) to obtain information for each building (floor, area, usage) and to estimate the structural type and fire-resistance performance for each building. For estimating casualties in a time series, we develop people flow data to grasp each individual's movement every 15 minutes throughout the year by using mobile phone GPS logs from 2012 throughout Japan from about 1.4 million sources of data.

Next, the fire probability from an earthquake is determined from ground motion intensity obtained from the Probabilistic Seismic Hazard Maps (PSHM) in each building area. PSHM is prepared in a 250m grid square as polygon data. As a result, fire-resistance performance and fire probability are used to calculate the fire spread probability. The probability of collapse for buildings is also estimated from the structural type and ground motion intensity. Then, we estimate casualties by combining the people flow data and each building's fire spread and collapse probability. This can be aggregated to any unit (municipality, prefecture, etc.) to get the numbers of casualties for each unit.

Finally, we analyze the result of damage from many scenarios and estimate the important damage in each region. Based on the important damage in each region, we compare the damage result of each scenario by using sparse modeling to select the most important scenarios.

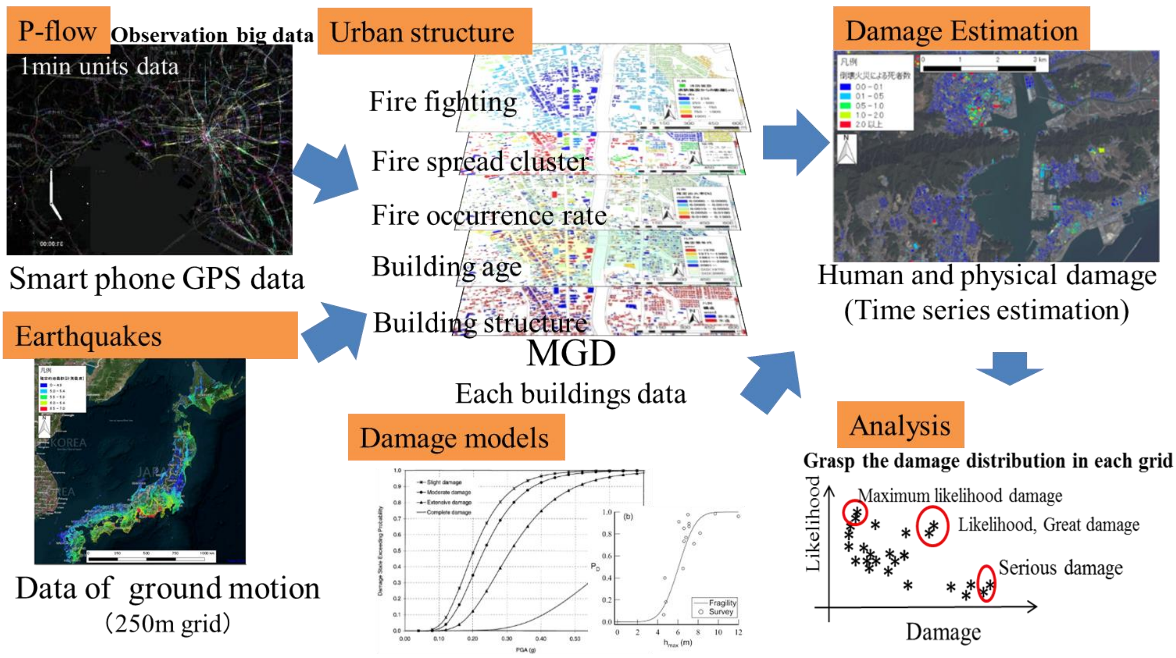
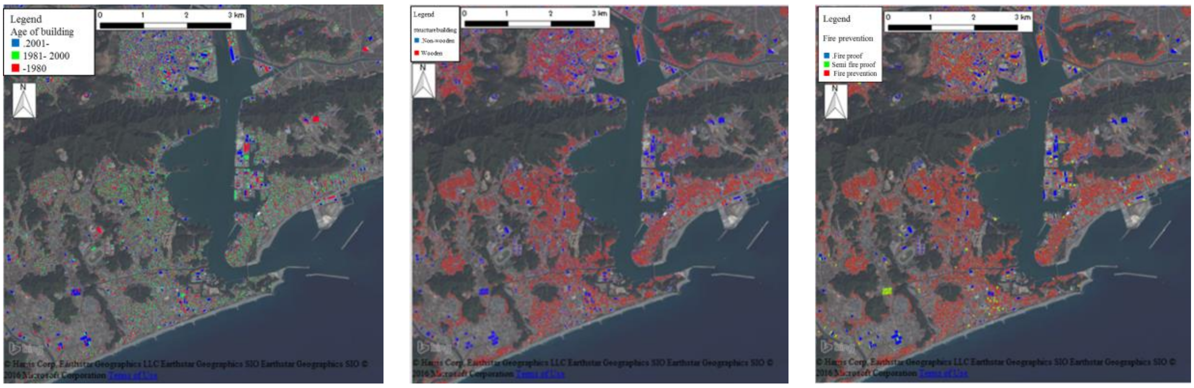


Figure1. Method of damage estimation for earthquakes in this study

Developing essential data

Building data

Building data related to the structure, age, and fire performance are obtained by using the method developed by Ogawa et al. (2013) and used for evaluating the damage. The information for each building is distributed into building data based on a random forest machine learning technique. See Ogawa at al. (2013) for more information. Figure 2 shows an example of building data for the estimation of earthquake damage.



(a) Building age **(b) Building structure** **(c) Fire resistance performance**

Figure 2. Building data for the estimation of earthquake damage

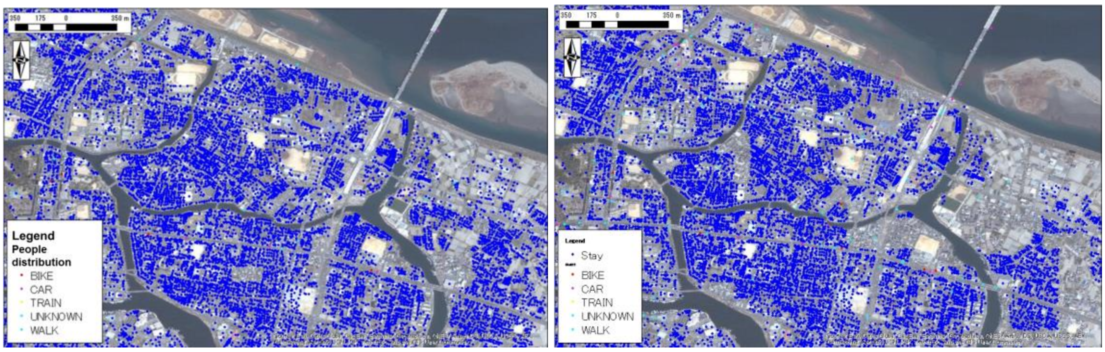
People flow data

In this study, we use data from mobile phone GPS logs in 2012 called "Congestion Analysis®" provided by ZENRIN DataCom Co. LTD. The source data from Congestion Analysis® are disaggregated data of mass people flows collected by the auto-GPS function on mobile phones on the NTT Docomo (NTT Docomo, INC., 2009). The data was obtained from phone users who permit the use of their information collected by mobile phone carriers. These data contain only measurements of time, location, and person ID, and do not reveal any information about the individual. The movement history of a specific individual cannot be monitored by the security processing. This is a large database that contains about 1.5 million users constructed from text data of approximately 9 billion records.

First, the GPS data was pre-processed to extract the stay point of the user from each position coordinate and observation time. The stay point defines the representative point of a user who remains for a certain time in a certain range. In this study, more than 15 minutes and a radius of 300m were the conditions of a stay. The stay point is defined as the central point of the maximum rectangle from the column of points during the staying period (Horanont (2010), Horanont et al. (2013), Hadano (2013)). Also, this data includes the holding time information from the arrival time and the departure time for each stay point. In addition, we estimated the work location and the home location for each data set from the stay points and the observation time. Regarding the transportation mode of each point, flags for walking, motorcycle, car, train, and staying are added to each observation point using the method of Apichon (2013). The method estimates the transportation mode according to the traveling distance and speed from the observation time, longitude, and latitude. The geometry of the railroad makes it possible to judge whether the observation point involves movement by railway.

Finally, we perform route interpolation between Point of Interest (POI). Considering the estimated traffic mode, if the traffic mode is walking, motorcycle, or car flow, we use the road network data. For a railroad flow, we use the rail network data. When connecting the observation point to the node of the road network, as the distance between the nodes becomes large, the error becomes large, so we consider the connection to the link. By searching for the nearest neighbor on the link, it is possible to make the error smaller than connecting to the node. Route interpolation uses a method of route interpolation of Person trips to GPS (considering the observation points between trips) developed by Sekimoto et al. (2011) and Kanasugi et al. (2014). In this method, instead of route interpolation with the shortest distance between trips, the route also considers observation points on the way between trips as connection points; this is a method of processing a route to a point observed between starting and ending points.

In addition, in order to match the GPS data to the population, we estimate the magnification coefficient from the estimated work locations and home locations. To estimate the magnification coefficient, we used statistical data for the number of people in the population and the number of employees. We use the 250m mesh data of the population census from 2010 for the residential population and the 250m mesh data from the 2010 economic census for the number of employees. The magnification number is estimated by dividing the residential population by the number of terminals at home places in the 250m mesh unit and the magnification coefficient is estimated by dividing the number of employees by the number of terminals at the work location. From the average of the two magnification coefficients, we get the final magnification coefficient. Figure 3 is the estimated time a different population that granted the expansion coefficient to the GPS data. By imparting a magnification factor to each data, it becomes possible to estimate the population distribution of the population rather than basing the simulations on the population distribution of a sample basis.



(a) Jan. 05, 2012, 8A.M. **(b) Aug. 10, 2012, 2P.M.**

Figure3. Estimated non-aggregated people flow data

Estimation of damage by Earthquakes

Precondition of estimation damage by earthquakes

In this study, physical and human damage was estimated for the period shown in Table 1. The number of assumed scenarios is as follows.

- Building damage (due to collapse and fire)

Since the fire greatly depends on the season, time, and wind speed, the disaster scenarios were set as follows. In winter and summer, the time slice is 1 hour. The wind speed was assumed to be 8 m/s, which is stronger than the average wind speed.

- Human damage

Since human damage is greatly affected by person flow at the year-end, New Year, and the festival and the usual period, the disaster scenarios were set as Table 1.

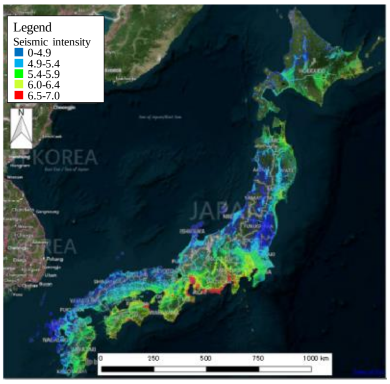
Table1. Assumed day, time and scene in this study

Month	Day	Scene
January	1〜5	Winter vacation
August	8〜12	Summer vacation
October	10〜17	Ordinary days
December	25〜31	Christmas

Estimation of building damage

First, we obtain the building information for the Probabilistic Seismic Hazard by the National Research Institute for Earth Science and Disaster Prevention (NRID). Second, we estimate the fire probability of each building. The Probabilistic Seismic Hazard is calculated by the probability of experiencing an excessive level of ground motion intensity within a target period at a given site. For this calculation, an evaluation is conducted by using a probabilistic approach on an epicenter. The occurrence probability, magnitude of all earthquakes that could occur in and around Japan, and the intensity of the ground motions caused by those earthquakes are evaluated with variance. We assumed ground motion 2% of excess probability more within 39 and 50 years (Figure 4 - Figure 7). Building data for the structure, age, and fire performances are developed by Ogawa et al. (2013) and used for evaluating the damage. Table 2 shows the fire probability according to the input ground motion (JMA seismic intensity scale) published by the Tokyo Fire Department (2007). We connect the Telepoint Data to the building and clarify the type of industry, and give a fire probability corresponding to the type of industry from Table 2. Finally, we assign the fire probability from the predicted ground motion and the building types.

In this study, the fire-spread probability of buildings of any different totaled-units is calculated using the following method (Kato et al. 2006). The clusters of fire spread are calculated by using the distance between buildings and fire performances.



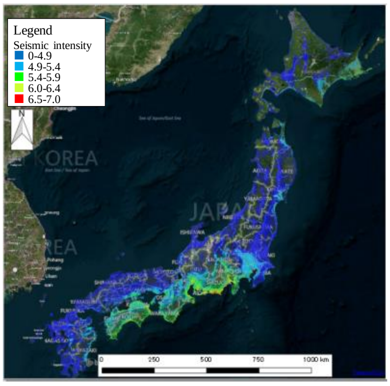
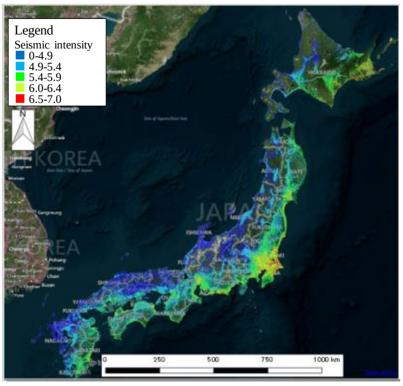


Figure4. Ground motion 2% of excess probability more within 50 years (Category 1)

Figure 5. Ground motion 39% of excess probability more within 50 years (Category 1)



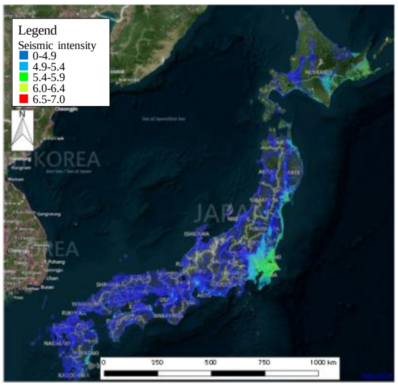


Figure 6. Ground motion 2% of excess probability more within 50 years (Category 2)

Figure 7. Ground motion 39% of excess probability more within 50 years (Category 2)

The burn down probability of each cluster of fire spread is given by Equation 1:

$$P = 1 - \sum_{i=1}^{n} (1 - p_i) \tag{1}$$

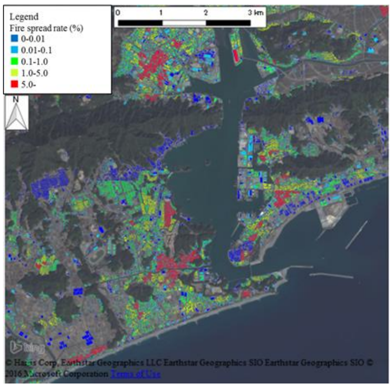
where P is the burn down probability of any different totaled-units, p_i is the fire probability of building i,. The fire risk is evaluated by calculating the number of burned down buildings and can extract high fire risk areas. The calculation is performed by using an approximate expression of the following formula to shorten the calculation time given by Equation 2:

$$P = 1 - \exp(-\textstyle\sum_{i=1}^{n} p_i) \tag{2}$$

Table 2. Fire probability (%) of predicted ground motion and the building types

Type of industry	JMA seismic intensity scale									
	5-lower		5-upper		6lower-		6-upper		7	
	DS	IW	DS	IW	DS	IW	DS	IW	DS	IW
Theater	0.0043	0.0039	0.0116	0.0125	0.0300	0.0305	0.0832	0.1005	0.1865	0.2956
Cabaret	0.0000	0.0041	0.0000	0.0100	0.0000	0.0242	0.0006	0.0860	0.0229	0.2902
Bar	0.0049	0.0058	0.0044	0.0086	0.0131	0.0231	0.0323	0.0771	0.0954	0.2292
Restaurant	0.0069	0.0073	0.0096	0.0106	0.0291	0.0306	0.0808	0,0858	0.2058	0.2168
Department store	0.0271	0.0211	0.1000	0.0774	0.2531	0.1928	0.7232	0.5694	1.8200	1.6071
Article store	0.0017	0.0014	0.0041	0.0042	0.0107	0.0105	0.0384	0.0458	0.3243	0.3866
Hotel	0.0148	0.0151	0.0644	0.0653	0.1600	0.1618	0.4566	0.4752	0.9663	1.0709
Apartment	0.0007	0.0012	0.0011	0.0027	0.0031	0.0070	0.0090	0.0249	0.0349	0.0757
Hospital	0.0045	0.0035	0.0093	0.0089	0.0247	0.0222	0.0701	0.0759	0.2191	0.4329
Clinic	0.0013	0.0014	0.0013	0.0034	0.0040	0.0082	0.106	0.0282	0.0495	0.1250
Dormitory	0.0014	0.0016	0.0028	0.0025	0.0075	0.0068	0.0228	0.0244	0.1116	0.1456
Nursery school	0.0025	0.0002	0.0033	0.0009	0.0095	0.0019	00.246	0.0094	0.0694	0.0393
Kindergarten	0.0019	0.0013	0.0019	0.0042	0.0056	0.0109	0.0137	0.0594	0.0431	0.1772
Elementary school	0.0083	0.0022	0.0136	0.0058	0.0374	0.0142	0.1002	0.0612	0.2989	0.2175
University	0.0037	0.0007	0.0062	0.0020	0.0170	0.0050	0.0458	0.0155	0.1263	0.0604
Public bath	0.0006	0.0009	0.0009	0.0027	0.0026	00064	0.0073	0.0225	0.0282	0.0874
Factory	0.0016	0.0013	0.0046	0.0046	0.0118	0.0117	0.0330	0.0564	0.0796	0.1529
Office	0.0024	0.0012	0.0069	0.0038	0.0176	0.0095	0.0496	0.0307	0.1208	0.0980
House	0.0007	0.0016	0.0007	0.0035	0.0021	0.0094	0.0058	0.0505	0.0274	0.1521

DS day time in summer, *IW* evening in winter.



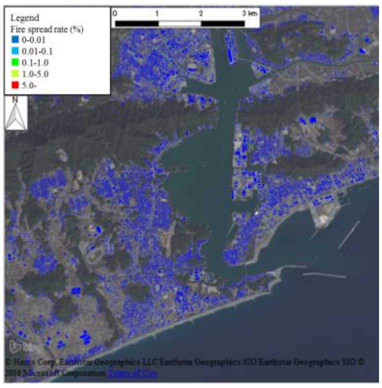
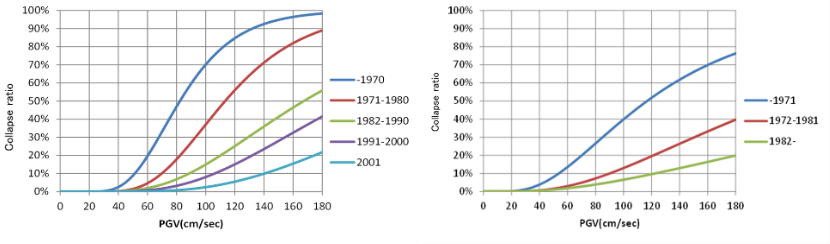


Figure 8. Example of estimated fire-spread result at 6 P.M. in winter
(2% of excess probability more within 50 years, category 1, Kochi city, Kochi prefecture, Japan)
Figure 9. Estimated fire-spread result at 6 P.M. in winter
(2% of excess probability more within 50 years, category 2, Kochi city, Kochi prefecture, Japan)

The occurrence probability of building damage is defined by using the vulnerability functions as an expression of relations between the peak ground velocity (PGV) and the building damage. The ground motion is obtained from PGV from a Probabilistic Seismic Hazard. We use the vulnerability function, which is often used to assess building damage in Japan. By referring to Murao and Yamazaki (2000) , we use two kinds of structures (wood-frame and non-wood-frame) considering the construction period. For a strong motion index x, the cumulative probability $P_r(x)$ of the occurrence of damage equal or higher than rank R is assumed to be lognormal given by Equation 3:

$$P_r(PGV) = \Phi((ln\ \ PGV - \lambda)/\xi \qquad (3)$$

where Φ is the standard normal distribution, and $\lambda$and $\xi$are the mean and the standard deviation of *ln PGV*. Figure 10 shows the interim vulnerability functions for wood-frame buildings and non-wood-frame buildings.



Wood-frame buildings Non-wood-frame buildings

Figure 10. Interim vulnerability functions of wood-frame buildings and non-wood-frame buildings with respect to PGV

Estimation of casualties

The casualties risk evaluation supposes that death is caused by a fire and a collapse in each building unit in each time frame. The calculation unit, based on each building, applies to the number of the de facto people in a building at the outbreak time. The method of the casualty risk is evaluated by the death rate with burned out probability and the number of the residents in the building. The death ratio by fire uses 0.046 (deaths/fire), the number of casualties per fire (except arson) in the 5 years over the whole country from 2005 to 2010. This ratio is also used by the Central Disaster Prevention Council (2012). The number of casualties per building is given by (4):

$$x_i = P_i * P_{f\ i} * R_i \qquad (4)$$

where x_i is the number of casualties of building *i*, P_i is the burn down probability of building *i*,P_{fi} is the death ratio by the fire of building *i*, and R_i is the number of people of building *i*.

The method of the casualty risk evaluation by a building collapse uses the death rate with the building damage ratio and the number of residents in the building. The death ratio by collapse is 6.8% in wooden buildings and 0.8% in non-wooden buildings; this is taken from the number of casualties per collapsed building for the five kinds of earthquake (Tottori earthquake, Tonankai earthquake, Nankai earthquake, Fukui earthquake, and Hanshin-Awaji earthquake). The number of casualties per building is given by (5):

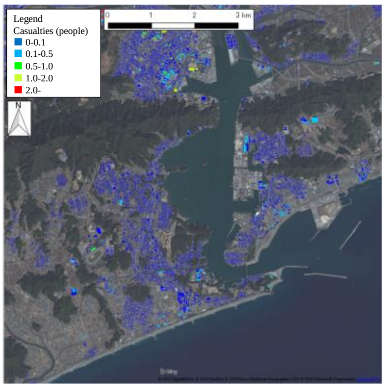
$$y_i = P_{ri} * P_{ci} * R_i \qquad (5)$$

where y_i is the number of casualties of a building *i*, P_{ri} is the building damage ratio of a building *i* , P_{ci} is the death ratio by collapse of building *i*, and R_i is the number of people in a building *i*. Thus, an estimate of the death ratio caused by a fire and a collapse is given by (6)

$$Nd_i = \sum_{i=1}^{n} \{x_i(1 - y_i) + (1 - x_i)y_i\} \qquad (6)$$

where Nd_i is the death ratio of a building *i*.

In this study, we estimate casualties for the period shown in Table 1. The assumed life scenarios are New Year, summer vacation, ordinary days, and Christmas. We input four types of probabilistic earthquake ground motion (2%, category 1 and 2 in 39 and 50 years.). Example results of the number of casualties by collapse and fire in each building selected from 10,000 scenarios are shown Figure 11 and Figure 12. By using GPS data, our method can estimate damage based on people flow 24 hours a day, 365 days a year, and also the damage distribution based on various hypocenter models of earthquakes. Results by inputs 2% of excess probability more within 50 years (category 1) are shown Figure 11 and Figure 12. Figure 13 shows a time series result of casualties by each ground motion in Kochi Prefecture due to collapse and fire (time slice: 15min., 10,000 scenarios) when we aggregated building unit data for the Kochi prefecture, Japan. Our method enables us to assess damage for any time frame and for any aggregate units, and thus it also enables us to evaluate human damage due to fire and building collapse caused by earthquakes in broad areas.



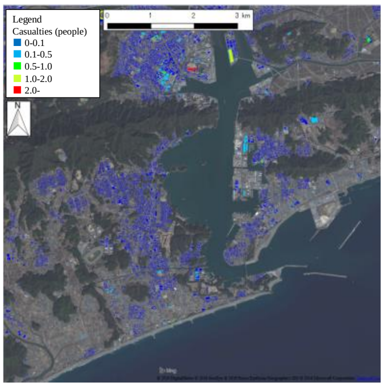


Figure11.The number of casualties by collapse and fire in each building

(0A.M., Jan. 01, 2012, 2% of excess probability more within 50 years, category 2)

Figure12. The number of casualties by collapse and fire in each building

(2P.M., Oct. 10, 2012, 2% of excess probability more within 50 years, category2)

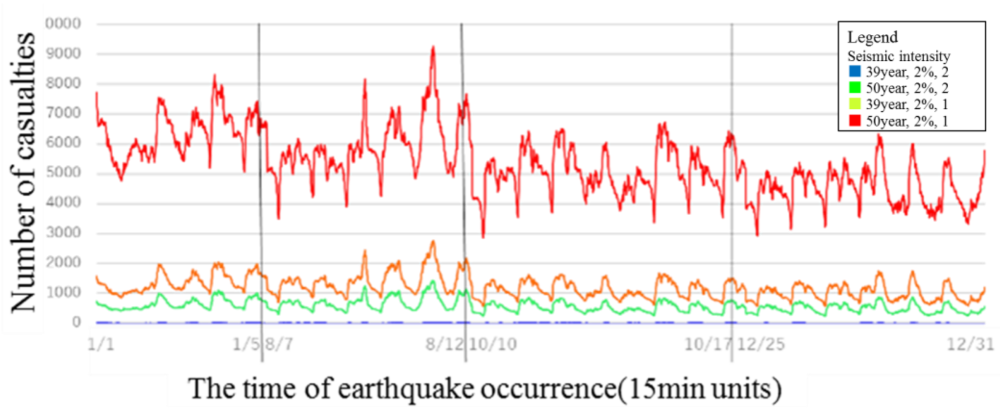


Figure 13. Time series result of casualties by each ground motion in Kochi Prefecture due to collapse and fire

(time slice: 15min.)

Extracting the significant damage based on estimated damage result

We extract important damage from the likelihood distribution of the damage by earthquakes by statistical processing of the damage estimation results of many estimated scenarios. Approximately 10,000 scenarios were calculated for the damage of collapse and fire by earthquakes. By using big data, the diversification and accumulation of data causes a large increase in the number of disaster scenarios. We cannot grasp which scenario is important by human cognitive ability via visualization of all scenario events. Thus, it is necessary to clarify the possible damage amount and the distribution of its likelihood by considering the enormous calculation result as counts of damage volume and to calculate the distribution of the damage amount and its likelihood, and to calculate the damage amount that is likely to occur from the enormous scenario. We will analyze the damage likelihood distribution in each region (500 m mesh).

In this study, we focus on the distribution of damage and the likelihood required from various scenarios and can estimate the important damage from this scenario.

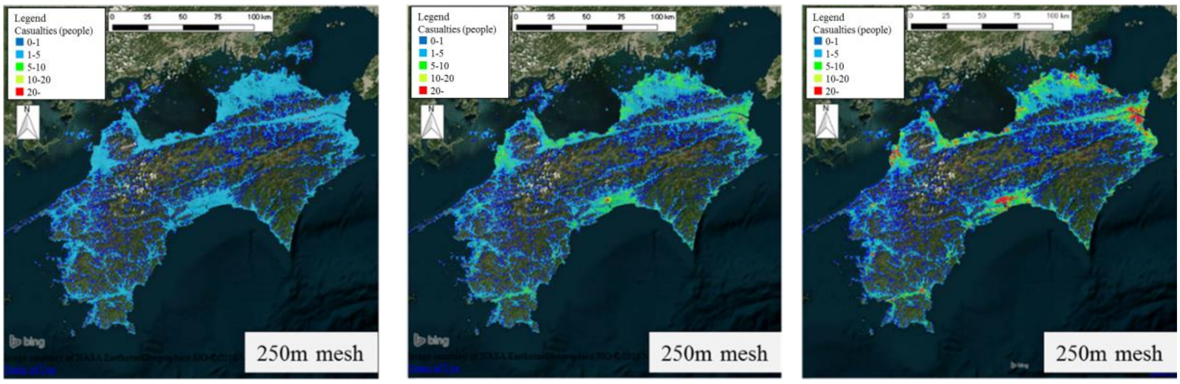
We consider 3 kinds of important damage as follows:

1) The highest likely damage amount: the most likely damage with maximum estimated likelihood.

2) The highest likely due to the damage that is greater than the average value: the damage is serious but likely to occur.

3) The greatest amount of damage: the most severe damage in many scenarios.

In the case of casualties due to collapse and fire, the most likely damage is shown in Figure 14 (a). The number of casualties aggregated for 500 m grid-cells (about 35000 mesh (only mesh with existing buildings)) throughout the study area had less than 5 people at the most likely damage sites. Figure 14 (b) shows the damage amount with a high likelihood of human damage caused by collapse and fire that is greater than the average value. In the case of a high likelihood that is above average, about 4000 grids have the number of casualties estimated as 5 to 10. Grids with 5 or fewer casualties are the most frequent and there are 54 grids that are estimated to have 50 casualties. In the case where the damage amount became extremely large (Figure14 (c)), there are many grids where casualties exceed 50 people. This is because of the dense building in urban areas.



(a) The highest likely damage amount **(b) The highest likely due to the damage that is greater than the average value** **(c) The greatest amount of damage**

Figure14. Estimated important damage in each grid

Extract the scenarios based on significant damage

We estimated the significant damage (maximum damage amount, maximum likely damage amount above the average, maximum likely damage amount) by analyzing the damage distribution for each region (grid) from the damage of the various scenarios. While the significant damage in each region is related to some scenarios, those scenarios are different in each region. For example, even if the maximum damage in some grid occurs at 18:00 (6 P.M), the maximum damage amount on another grid may not necessarily be on the same date and at the same time. This is because the wooden building rate and the human flow vary according to attributes in each region. Therefore, focusing on the objective (dependent) variable for the important damage in each region and the independent variable for the damage of many scenarios, we extract scenarios which explains the important damage. In this study, we assumed that the important damage in each region related to several scenarios from various scenarios (Figure 15).

Therefore, if objective variables such as important damage for each region can be explained with a small number of scenarios, the many remaining scenarios are sparse and those scenarios can be explained under a minimum mean square error from sparse modeling. In this study, we extract scenarios that explain the maximum likely damage, the maximum likely damage above the average, and the maximum damage from the 9984 scenarios using a Lasso regression.

The method used in this study uses Lasso regression of sparse modeling. The regression equation is expressed by Equation (7). The parameter β is estimated by Equation (8).

$$y = \sum \beta_i x_i + \beta_0 \tag{7}$$

$$\min_{(\beta_0,\beta)\in R^{p+1}} R_\lambda(\beta_0,\beta) = \min_{(\beta_0,\beta)\in R^{p+1}} \left[\frac{1}{2N}\sum (y_i - \beta_0 - x_i^T\beta)^2 + \lambda P_\alpha(\beta)\right] \tag{8}$$

where

$$P_\alpha(\beta) = (1-\alpha)\frac{1}{2}\|\beta\|_{l_2}^2 + \alpha\|\beta\|_{l_1} \tag{9}$$

$$= \sum_{j=1}^{p}\left[\frac{1}{2}(1-\alpha)\beta_j^2 + \alpha|\beta_j|\right]. \tag{10}$$

Equations (9) and (10) are penalty terms, and the Lasso regression is obtained with α = 0. λ is called the Complexity Parameter, and when λ is 0, it becomes a normal least squares method. The parameter β is estimated to be small when the influence of the penalty becomes strong as seen in Equation (9). If λ (the Complexity

Parameter) is small, the model becomes a complicated model and it will have many variables. If λ is large, the model becomes simple and the number of variables will be small. Lasso can perform estimation and variable selection at the same time, therefore it is useful to select variables with high dimensions from small sample data, but when considering variable selection of data that have high correlation between variables, Lasso cannot capture this correlation and support appropriate variable selection.

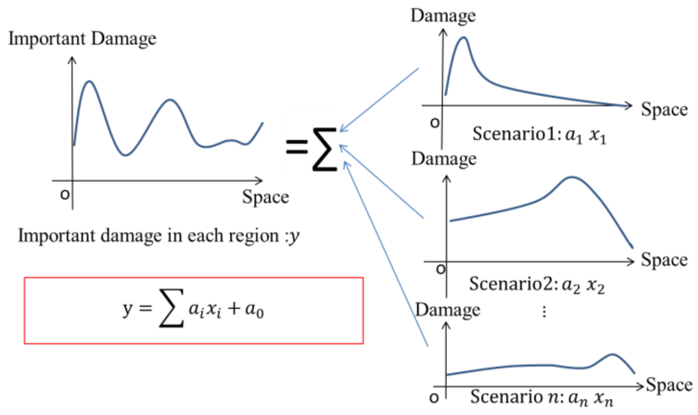


Figure 15. Conceptual diagram for extracting a scenario describing a significant damage amount.

Results

The estimation results are shown in Table 3. In the case of MSE minimum, 2 scenarios were selected from the 9984 scenarios for the case of maximum likely damage. In case of maximum likely damage above, 36 scenarios were selected out of 9984 scenarios. In the case of maximum damage amount, 27 scenarios were selected out of 9984 scenarios. In the case of the maximum damage amount, all the selected earthquake ground motions are of the 50 years 2% scenario 1 (seismic motion assuming a huge earthquake such as the Nankai Trough earthquake), and midnight in January and October is selected as the time of fire (Table 3). This indicates that the damage will increase at times when there are many people staying for a long time overlapping with the time of fire and the dinner time period. Also, August 9th is selected when three major festivals of Shikoku in the Kochi Prefecture, including the "Yosakoi Festival " and "The Kochi City Fireworks Festival" are held, and many more people from other prefectures gather than usual. The event scenario was selected but it was not a consideration in the previous study such as Central Disaster Prevention Council, (2012). Thus, the maximum damage for each area in the prefecture is explained as the scenario of the time of fire being in January, October, and the time of festivals.

In the case of the maximum likely damage above the average value, 39% of excess probability more within 50 years was chosen a lot, but a time zone with a high fire utilization rate such as evenings and mornings was selected (Table 3). This indicates that greater than average damage tends to occur in the time zone of fire during weekdays in October, because the parameters of the scenario are large.

In the case of maximum likelihood damage, all the selected scenarios were ground motion with 2% of excess probability more within 50 years (scenario 1), but the scenario of 12 o'clock in October was selected. The damage amount at this time was not more severe than other scenarios and it is considered that there are fewer scenarios selected than other important damage because the damage is small in every area.

Thus, we proposed a method to extract scenarios for important damage by using sparse modeling. Applying the advanced damage estimation model to all scenarios is unrealistic because of the required computational resources. By applying the advanced damage prediction model efficiently to the significant scenarios, it becomes efficient to estimate the damage prediction. In addition, experts previously determined by heuristic methods that the maximum damage amount occurs at 18:00 in winter but this result should be clarified from various scenarios, and in this research, we propose a method to select such important scenarios.

Table 3. Results of extracting the scenario for each important damage

The highest likely due to the damage that is greater than the average value					Most likely damage					Maximum damage				
Probability	Scinario No.	Occurrence date	Occurrence time	SM-value	Probability	Scinario No.	Occurrence date	Occurrence time	SM-value	Probability	Scinario No.	Occurrence date	Occurrence time	SM-value
39%	1	October-17	7:15	11.24249	2%	1	October-17	12:00	0.044244672	2%	1	October-17	10:00	0.438656
39%	1	October-17	7:45	7.908934	2%	1	October-17	12:45	0.035830529	2%	1	December-17	19:45	0.376042
39%	1	December-17	8:00	7.420919						2%	1	January-17	12:30	0.323778
39%	1	August-17	14:45	6.90713						2%	1	October-17	18:45	0.274424
39%	1	December-17	9:45	6.713281						2%	1	October-17	12:00	0.243085
39%	1	December-17	6:00	6.643027						2%	1	August-17	21:00	0.234557
39%	1	August-17	7:45	5.831148						2%	1	January-17	6:15	0.225371
39%	2	August-17	17:45	5.60145						2%	1	January-17	12:15	0.187838
39%	2	October-17	2:45	5.157977						2%	1	October-17	18:45	0.184874
39%	1	October-17	12:15	4.319525						2%	1	January-17	3:00	0.142111
39%	2	January-17	8:30	3.771216						2%	1	December-17	8:03	0.13171
39%	1	August-17	18:15	3.077024						2%	1	January-17	21:00	0.101121
39%	2	October-17	8:00	2.777986						2%	1	January-17	11:30	0.09988
39%	1	January-17	19:00	2.722213						2%	1	August-17	8:00	0.090185
39%	2	December-17	14:45	1.938811						2%	1	January-17	15:15	0.082369
39%	2	August-17	22:30	1.84396						2%	1	August-17	20:45	0.080362
39%	2	October-17	10:30	1.673142						2%	1	October-17	4:45	0.077799
39%	2	October-17	19:30	1.087428						2%	1	October-17	19:30	0.07522
39%	1	August-17	7:30	0.24137						2%	1	January-17	12:45	0.074114
39%	1	October-17	0:30	0.236362						2%	1	January-17	12:30	0.045948
39%	1	October-17	3:30	0.163318						2%	1	January-17	9:00	0.042458
39%	1	August-17	12:00	0.132921						2%	1	October-17	12:00	0.041706
2%	1	December-17	7:30	0.118741						2%	1	January-17	23:15	0.035377
2%	1	October-17	4:15	0.117034						2%	1	January-17	2:15	0.032316
39%	1	December-17	23:00	0.111363						2%	1	January-17	1:00	0.017237
39%	1	December-17	22:30	0.108575						2%	1	October-17	11:15	0.01507
39%	2	January-17	19:15	0.103867						2%	1	January-17	11:30	0.01458
2%	1	October-17	6:45	0.083615										
2%	1	October-17	12:45	0.064554										
2%	1	January-17	7:15	0.057892										
2%	1	January-17	7:00	0.003149										
2%	1	October-17	17:15	0.001563										
2%	1	January-17	4:30	0.000648										
2%	1	January-17	3:45	0.000632										
2%	1	December-17	23:00	7.46E-05										

CONCLUSION

This study developed data which can be used to model detailed people flow 365 days a year, 24 hours a day, in 15-minute units from micro geodata such as GPS data from smart phones, residential maps, phone books, etc., An environment for integrated damage estimation for building damage caused by collapse and fire in building units by using micro geodata was also developed. In addition, the developed data is used to estimate human damage by earthquakes in various scenarios and integrally in each building unit. Our damage estimation environment can also be applied to detailed estimation models such as fire-spread simulation models and multi agent simulation models. Our method is unique in that it enables us to assess damage for any time frame and any aggregate units, and thus it also enables us to evaluate human damage due to fire and building collapse caused by earthquakes in broad areas by aggregating the evaluation of each building scale. A statistical analysis method is proposed to extract significant damage amounts by clarifying the damage distribution for each region from various scenario estimation results. In addition, by using sparse modeling, we proposed a method to select important scenarios from significant damage in each region.

Since we have not verified the accuracy of the damage estimation in this research, this must be established in future research. Also, previous damage assessment has not been verified estimated damage result by earthquakes, but we can compare with damage data from past earthquakes if detailed survey data from past earthquakes can be obtained. In addition, as there are some factors of error in the simulation process (e.g. the accuracy of the base data, the accuracy of the prediction model, the accuracy of the seismic motion), when precision estimation models are applied in the future, it is important to prepare the essential data with high accuracy. In addition, this research provides only one result of analysis by sparse modeling, and it is necessary to compare the results of the extracted scenarios with the damage results with each event to change the analysis unit and check how the result changes under these new parameters.

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ACKNOWLEDGMENTS

We would like to thank CSIS (joint research No. 448) and ZENRIN DataCom Co., LTD for providing the Congestion Analysis®.

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Calling 311: evaluating the performance of municipal services after disasters

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ABSTRACT

As part of a movement towards enabling smart cities, a growing number of urban areas in the USA, such as New York City, Boston, and Houston, have established 311 call centers to receive service requests from their citizens through a variety of platforms. In this paper, for the first time, we propose to leverage the large amount of data provided by these non-emergency service centers to help characterize their operational performance in the context of a natural disaster event. We subsequently develop a metric based on the number of open service requests, which can serve as the basis for comparing the relative performance of different departments across different disasters and in different geographic locations within a given urban area. We then test the applicability and usefulness of the approach using service request data collected from New York City's 311 service center.

KEYWORDS

Resilience, Municipal Departments, 311 Service Center, Disaster, Critical Infrastructure

INTRODUCTION

Modern societies increasingly rely on systems that provide basic services to them, such as electric power systems, water supply systems, healthcare, transportation, and communication systems. These interdependent critical infrastructure systems serve as the backbone of a nation's security, economy, and health (Department of Homeland Security, 2016). The 2003 Northeast blackout event highlights the devastating effects that the failure of one critical infrastructure can have on society, and it emphasizes the importance of being prepared to face such natural and manmade disasters: "The outage stopped trains, elevators and the normal flow of traffic and life…water supplies [also] were affected because water is distributed through electric pumps…" (CNN, 2003). A number of different industries, including the automotive, airline, and telecommunications sectors, also were disrupted by the outage (WSJ, 2003).

According to the U.S. National Academies, disaster resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to the disruptive event (National Academies, 2012). This definition of disaster resilience can be applied at different levels of a society, from an individual, to a community, to an entire metropolitan area, and even to an entire nation. Efforts to improve societal resilience have gained a lot of attention over the past few decades, particularly after recent tragedies such as Hurricane Katrina in 2005, the Japanese earthquake and tsunami in 2011, and Hurricane Sandy in 2012 (Cutter, 2016).

In spite of growing research about the concept of disaster resilience, however, there are still few rigorous quantitative methods available for evaluating the resiliency of systems against disasters at different levels of a society. Such methods have the potential to provide valuable information about how the system reacts and responds to the occurrence of a disaster and thus support decision makers in comparing different approaches for improving resilience. In an attempt to contribute to this important area of research, this current study focuses on quantitatively evaluating the disaster resilience of one of the most important service providers after disasters, i.e. ***municipalities***.

Providing and maintaining an appropriate level of public services is the primary responsibility of a municipality to its citizens. Some of these services, such as maintaining roadways and providing access to water and sewer systems, become even more important after disasters, and it is critical that a municipality have access to accurate and up-to-date information about the demand for such services. This has become much easier with advances in information and communication technologies that allow citizens to make requests of municipal service providers directly, such as by calling 311 or by accessing a dedicated website (such as http://www1.nyc.gov/311/).

The following discussion seeks to leverage the increasing availability of such municipal service data by exploring the number of open service requests as a measure of performance of a municipal service provider, both before and after a disaster event. This new measure will allow us to compare the relative performance of different departments across different disasters and in different geographic locations within a given urban area. A growing number of big cities have established 311 call centers to receive such service requests and our first goal in this paper is to demonstrate the potential of using the large amount of data generated from these centers to characterize the disaster resilience of a municipality.

In the following sections, we begin by briefly summarizing related studies about evaluating disaster resilience. We then introduce the dataset upon which our analysis is based: the complete set of municipal service calls received by New York City's 311 call center between 2004 and 2015. We then apply the methodology to the task of evaluating the resiliency of one of NYC's municipal departments, in response to several different disaster events occurring between 2010 and 2012. We conclude the discussion with a summary of the current findings and a statement of future work.

LITERATURE REVIEW

Disaster resilience has received a lot of attention from both policymakers and academics in recent years. For example, in 2009, a new program called the Regional Resiliency Assessment Program (RRAP) was launched by the U.S. Department of Homeland Security (Department of Homeland Security, 2015). The aim of the new program was to assess resiliency of U.S. critical infrastructure within defined geographic areas, in order to address resilience issues that could have significant consequences.

Even with increased attention on resilience, however, there still are few rigorous quantitative methods available for evaluating the level of disaster resilience that is inherent in or exhibited by different levels of a society. In an attempt to address this gap, some researchers adopt a stationary view of resilience and construct social and economic indicators, such as the percentage of educated population within a community, demographics, and average annual income, as component measures of a society's disaster resilience (see for example, Norris et al., 2008 and Cutter et al., 2008). Although these indicators provide an overview of a society's capacities to deal with disaster events, they do not capture the dynamic aspects of the resilience concept. Other researchers thus adopt a more active systems viewpoint to quantify disaster resilience (Zobel, 2014; Pant et al., 2014; MacKenzie and Zobel, 2016). In this study, we consider municipalities as a type of complex system and adapt this systems resilience viewpoint to evaluate their resilience performance against disaster events.

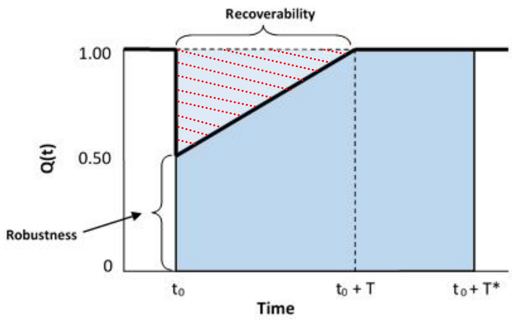

Figure 1. Predicted resilience (adapted from Zobel, 2011)

As one of the first attempts to analyze a system's ability to face a disruptive event, Bruneau et al. (2003) proposed examining a response curve that provides changes in a system's performance over time. Figure 1 shows an example of such a response curve for a system that experiences a disruption at time t_0, where $Q(t)$ shows the system's functionality at time t. Bruneau et al. (2003) proposed to use the area above the response curve (for example, the red shaded area in Figure 1) to measure the *loss of resilience* in the system due to the disruption. They named the shaded area the *resilience triangle* and argued that when the resilience triangle is smaller, the system is more resilient.

Zobel (2010, 2011) revisited this original concept and introduced a new measure of resilience, known as *predicted resilience* (R), which can evaluate a system's resilience directly instead of indirectly. He defined the predicted resilience as the area beneath the response curve after it is normalized by the corresponding area that would have been realized if there had been no disruption. For example, considering a sudden-onset disruption and linear recovery as shown in Figure 1, the predicted resilience can be calculated using the following formula:

$$R = 1 - \frac{XT}{2T^*} \tag{1}$$

where X is equal to the loss suffered at time t_0 and T^* is a user-defined upper bound on the recovery time.

Zobel (2014) further argued, however, that the sudden-onset disruption and linear recovery do not always match the reality of a disruption profile, and he developed a general predicted resilience function that is applicable for different types of disruptive events and recovery functions, a version of which is shown in formula 2.

$$R = \frac{\int_{t=t_0}^{t=t_0+T^*} Q(t)dt}{T^*} \tag{2}$$

Subsequently, this measure of resilience and its extensions have been widely applied to measure the resilience of systems in different contexts, such as interdependent infrastructure and industry sectors (Pant et al., 2014; Baghersad and Zobel, 2015), supply chains (Spiegler et al., 2012; Torabi et al., 2015), and transportation systems (Adjetey-Bahun et al., 2016). In this paper, we will adapt this generalized predicted resilience formula to calculate the resilience of *municipalities* against different disaster events. This process is described in the analysis section of the paper.

NEW YORK CITY SERVICE REQUEST DATASET

New York City, like several other big cities such as Boston and Houston, has created a specific call center to receive nonemergency city service requests, named NYC311. The main mission of the NYC311 service is "*to efficiently respond to inquiries and requests from residents, businesses, and visitors by providing reliable information and accurately processing requests for city services 24 hours a day, 7 days a week*" (NYC global partners, 2011). This center allows New Yorkers to request all variety of nonemergency city services through a number of different platforms: an easy-to-remember phone number (311), an online site, a smartphone app, social media, text messaging, video relay services, and TTY/text telephone service. The NYC311 service was launched in 2003, and it has served as a significant step towards New York City's goal of becoming a smart city. Over 120 million calls had been received by the center by 2012, and these service requests have been made publically available through New York City's Open Data initiative (https://nycopendata.socrata.com/).

As the basis for our analysis of municipal services, we collected all available 311 service requests recorded on the NYC Open Data website for the period covering years 2004 – 2015: the dataset includes a total of 23.5 million

Table 1. Selected 311 service request attributes

Attribute name	Description
Created Date	Date and time the record was created
Closed Date	Date and time the record was closed
Agency Name	Specific agency name
Complaint Type	Category of complaint type
Descriptor	Detailed description of complaint
Incident Zip	Zip code of incident location
Incident Address	Street address of incident location
City	City of incident location
Borough	Borough of incident location
Due Date	Date and time the request is due
Resolution Description	Description of call resolution update
Latitude	Latitude of incident location
Longitude	Longitude of incident location

Table 2. Top six agencies based on number of service requests in 2012

Agency	Agency name	No. of calls in 2012	Top five complaint types
HPD	Department of Housing Preservation and Development	562,761	Heating, General Construction, Plumbing, Paint – Plaster, Non Construction
NYPD	New York City Police Department	294,053	Noise – Residential, Blocked Driveway, Illegal Parking, Noise – Commercial, Noise - Street/Sidewalk
DOT	Department of Transportation	256,972	Street Light Condition, Street Condition, Traffic Signal Condition, Broken Muni Meter, Sidewalk Condition
DEP	Department of Environmental Protection	147,084	Water System, Sewer, Noise, Air Quality, Hazardous Materials
DSNY	Department of Sanitation	112,008	Dirty Conditions, Sanitation Condition, Graffiti, Missed Collection, Sanitation Condition
DPR	Department of Parks and Recreation	106,055	Damaged Tree, Overgrown Tree/Branches, Root/Sewer/Sidewalk Condition, New Tree Request, Maintenance or Facility

unique service requests. Each unique service request includes characteristics of the service request such as the time and date of the request, the agency called, the complaint type, the street address, the borough, how and if the request was resolved, the resolution date, and the latitude and longitude of the incident, as shown in Table 1.

These service requests include a variety of service types (more than 130 types) from different municipal departments. Table 2 shows the top six agencies that received service requests, along with each one's top five complaint types, in terms of the number of service requests received in 2012. The Department of Housing Preservation and Development (HPD), the New York City Police Department (NYCPD), the Department of Transportation (DOT), and the Department of Environmental Protection (DEP) received the most service requests during this time period. The top 12 complaint types overall (based on number of service requests) for this same year are also reported in Table 3. The last column of Table 3 shows the ratio of the number of service requests related to each complaint type to all service requests received by the agency in 2012. This indicates that Heating and General Construction complaints include more than half of the complaints received by HPD. Table 3 also shows that *Damaged Tree* complaints, in the Department of Parks and Recreation (DPR), have the highest ratio across all departments in 2012.

Table 3. Top 12 complaint types in 2012

Rank	Complaint type	Agency	N. of calls in 2012	% of overall services
1	Heating	HPD	182,974	32.51
2	Noise - Residential	NYPD	127,524	43.37
3	General Construction	HPD	112,436	19.98
4	Street Light Condition	DOT	93,866	36.53
5	Plumbing	HPD	91,192	16.20
6	Paint - Plaster	HPD	77,287	13.73
7	Street Condition	DOT	67,050	26.09
8	Non Construction	HPD	60,055	10.67
9	Water System	DEP	57,600	39.16
10	Blocked Driveway	NYPD	50,645	17.22
11	Damaged Tree	DPR	50,394	47.52
12	Traffic Signal Condition	DOT	47,484	18.48

Table 4. The seven disaster events from 2010 to 2012

Event ID	Event description	Date of Event
Event 1	2010 Nor'Easter	13-14 Mar. 2010
Event 2	Brooklyn / Queens tornadoes	16 Sep. 2010
Event 3	N. American Blizzard	25-27 Dec. 2010
Event 4	Hurricane Irene	28 Aug. 2011
Event 5	Major Snowstorm	31 Oct. 2011
Event 6	Hurricane Sandy	29 Oct. 2012
Event 7	2012 Nor'Easter	7 Nov. 2012

ANALYSIS

We start our analysis by focusing on the number of service requests received both during and after several major natural disasters in New York City from 2010 to 2012. We found a total of seven major disaster events reported during this time period; some of these disaster events were localized, like the tornadoes that hit Brooklyn and the Bronx in 2010, and some of them, like Hurricanes Irene and Sandy, impacted the entire New York City metropolitan area. Table 4 shows these seven events and date of their occurrence. Our discussion focuses on calls related to the *Damaged Tree* category of complaints, which exhibits some interesting behaviors in response to the different disasters. As mentioned above, this category of calls also includes almost half of the service requests received by DPR and therefore it is a reasonable proxy of that agency's overall performance.

Figure 2 shows the daily number of service requests related to the *Damaged Tree* complaint type between 2010 and 2012. It is easy to see that number of calls associated with every event, except for Event 3, the North American Blizzard of December 2010, increases in conjunction with that event. Specifically, Figure 2 implies that Hurricane Sandy (event 6), Hurricane Irene (event 4), and the 2012 Nor'Easter (event 7) had the most impacts on the number of service requests related to the *Damaged Tree* complaint type.

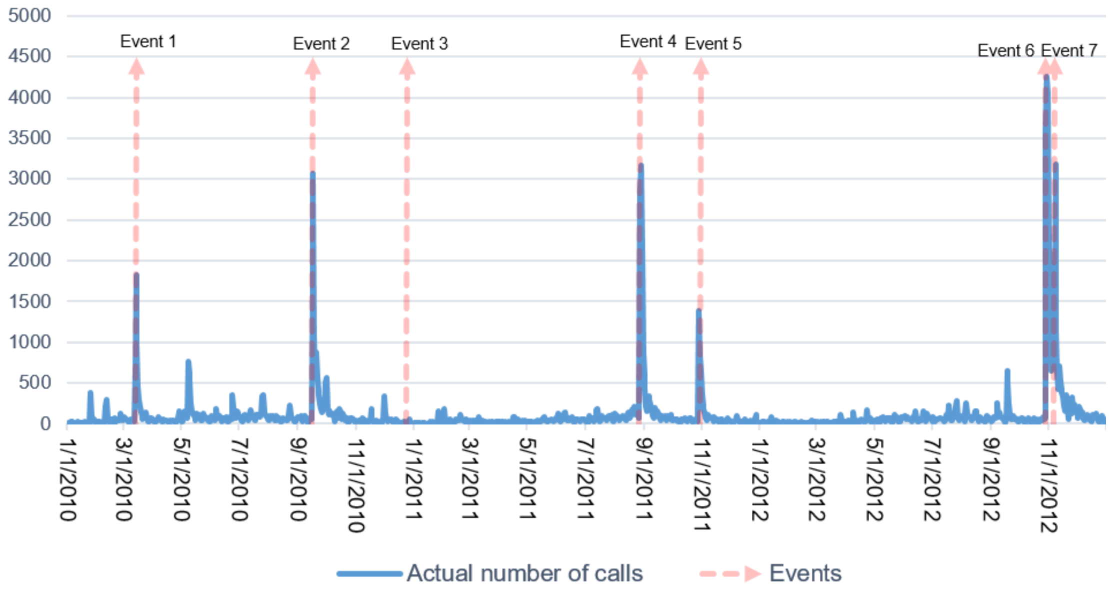

Figure 2. Number of *Damaged Tree* service requests

This measure of the number of service requests over time describes the effect of disasters on the community, in terms of how citizens are reacting to changes in their physical environment. However, it does not directly provide any information about the related operational performance of the municipal departments during and after those same events. In order to analyze the performance of these agencies, therefore, we introduce a new measure: the number of open service requests per day, which is the number of prior service requests that are still in process on the day in question. This measure is calculated using the created date and closed date attributes of the individual service requests, and it indicates the ability of the respective department to deal with service requests over time.

Figure 3 illustrates the new measure by showing the number of open service requests per day for the *Damaged Tree* complaint type. It is straightforward not only to see that six out of seven events have a significant impact on the number of open service requests but also to see that the different events had different amounts and types of impacts on the agency's ability to address its open workload.

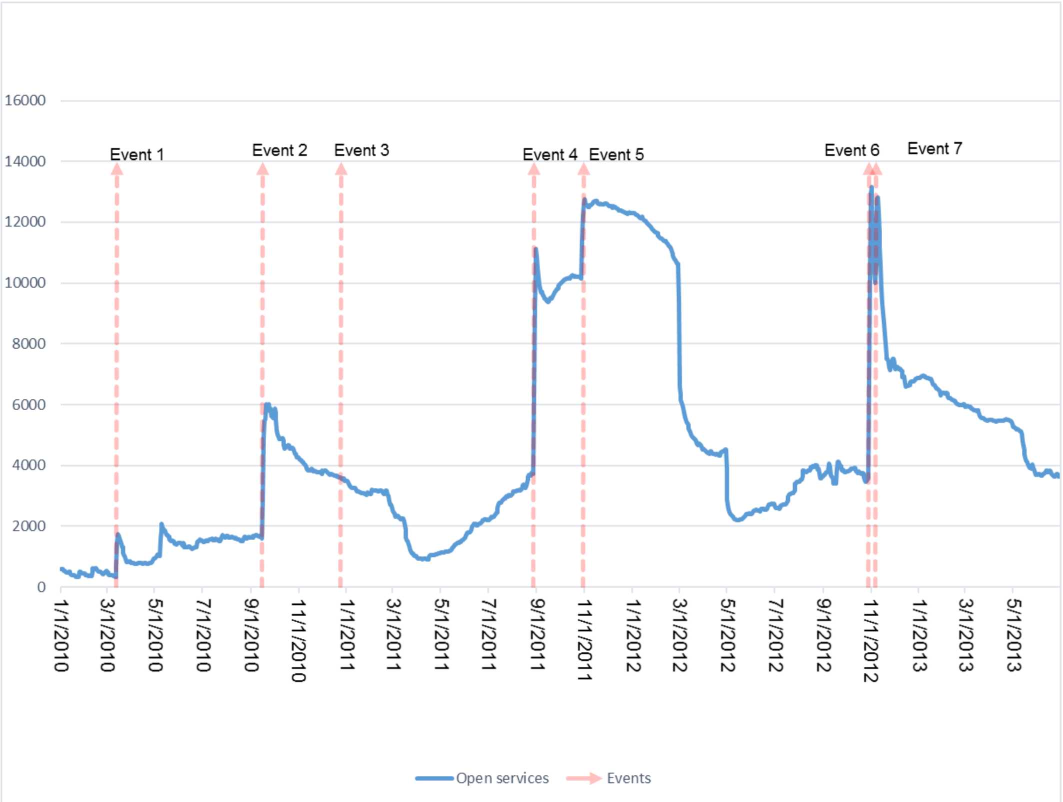

Figure 3. Number of open service requests for damaged tree complaint type

In order to create a quantitative measure by which the agency's performance can be compared across the seven events, we calculate the relative ability of the system to resist and then quickly recover from the impact of each event, or its resilience. Specifically, we adapt the notion of predicted resilience, as proposed by Zobel (2010), and measure the relative loss in performance level over a pre-specified time interval (in this case, two months). We consider that the system has recovered from a given event if it is able to return to the number of open calls that existed immediately before that event occurred. If the number of open service calls does not come back to its original level after two months, however, then we simply calculate the total amount of loss over time during those two months. As an example of this, the total loss of performance over time for event 2 is highlighted in Figure 4. The two month time frame was chosen so that there was enough time elapsed to capture the system response. A longer time period might capture the longer term effects of a given disaster, yet it could also lead to more frequent occurrences of multiple events occurring during the same interval. Regardless of the time frame, however, as long as the resilience values are interpreted with respect to that specific interval, the implications of the results will be consistent with previous research.

To calculate the relative amount of resilience reflected in the system response during the chosen time period, the area of loss (A_i) for event i is therefore divided by the maximum observed loss in performance (relative to the initial number of open calls) and the length of the chosen time interval (T^* = 2 months) in order to normalize the results. The resulting ratio is then subtracted from one:

$$R(i) = 1 - \frac{A_i}{X_{max}T^*} \quad (3)$$

This provides an analogous result to the formulation of the predicted resilience function that was given in equation (2). Furthermore, it extends the previous work of Zobel (2014) by capturing loss as a positive (rather than negative) deviation from the default performance curve.

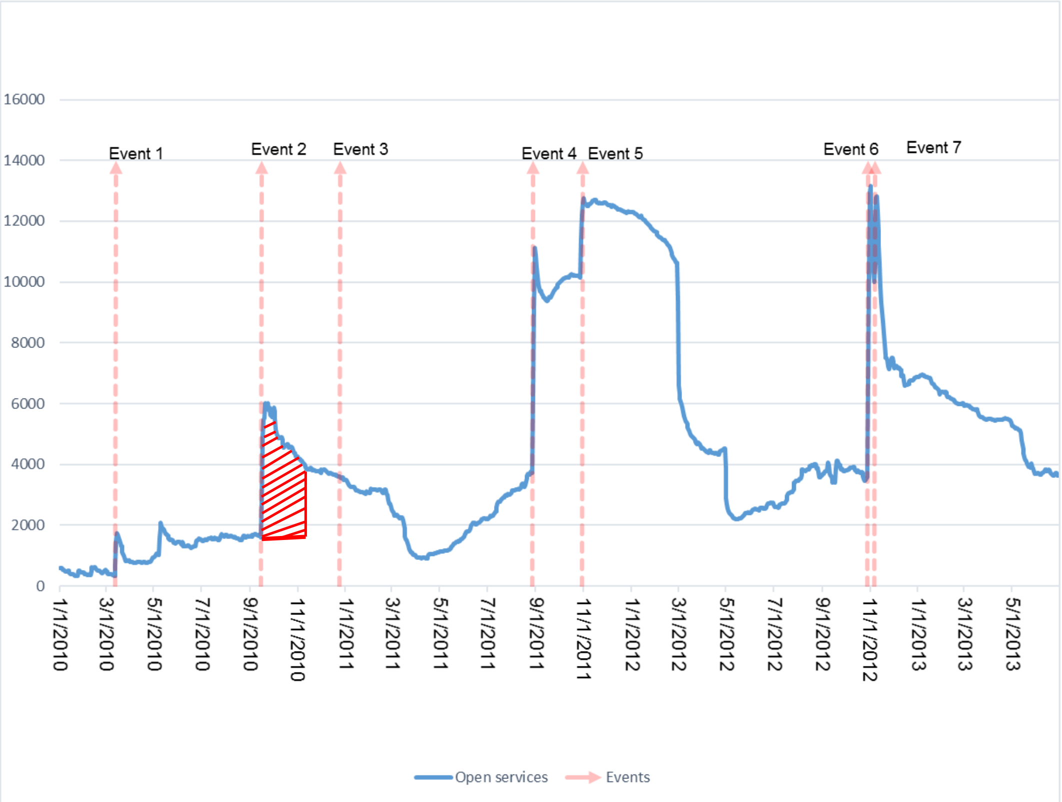

Figure 4. Example of loss of performance area

Table 5 shows the resulting resilience values related to the *Damaged Tree* complaint type for the seven different disaster events, given the chosen two month time window. The results indicate that the resilience values were lowest for Hurricane Irene (event 4), Hurricane Sandy (event 6), and the 2010 tornadoes (event 2), respectively.

Comparing these results with those obtained from the number of incoming service requests (Figure 1) gives us some insights about operational performance of the municipal department. For example, although the number of service requests was highest for Hurricane Sandy, this event did not actually have the largest impact on the number of open service requests. Instead, the worst resilience value is related to Hurricane Irene, which had the second highest increase in number of service requests. The cause of this big change in performance from Hurricane Irene to Hurricane Sandy easily could be due to gaining experience from the first hurricane or it could be due to other operational factors that may require further review by managers.

Table 5. Resilience value with respect to *Damaged Tree* open calls

Event ID	Event description	Resilience value (%)
Event 1	2010 Nor'Easter	92.89
Event 2	Brooklyn / Queens tornadoes	67.93
Event 3	N. American Blizzard	100.00
Event 4	Hurricane Irene	37.37
Event 5	Major Snowstorm	96.91
Event 6	Hurricane Sandy	51.51
Event 7	2012 Nor'Easter	98.01

CONCLUSIONS AND FUTURE WORK

Municipalities are responsible for providing an appropriate level of public services to their citizens. Some of these services, such as maintaining roadways and providing access to water and sewer systems, become even more important after disasters. A growing number of big cities have established 311 call centers to receive service requests from their citizens, and the data generated through some of these non-emergency service centers are available for public use. In this paper, we propose that using this data to analyze the performance of municipal departments during and after disaster events can provide valuable information to a municipality's decision makers, and thus help to improve its resilience.

As the first step towards realizing this goal, we developed a new metric based on the number of open service requests to measure the performance of a municipal service provider both before and after a disaster event. This new measure allows us to compare the relative performance of different departments across different disasters and in different geographic locations within a given urban area. We tested the applicability and usefulness of the measure by using real data collected from New York City's 311 service center, and specifically analyzed characteristics of the *Damaged Tree* complaints, within the Department of Parks and Recreation, during seven major disaster events during 2010 to 2012. These initial analyses revealed several interesting insights. For example, we found that although Hurricane Sandy had the most impact on the number of new service requests received, it did not have the worst overall impact on operational performance. The results instead indicate that Hurricane Irene had the worst impact on operational performance, even though its associated impact on the number of new service requests was not as high.

There are a number of possible extensions to the work presented here. For example, an alternative performance measure that might have interesting characteristics would be the ratio of the number of open service requests to the number of new service requests. By incorporating the number of new service requests, this new measure would eliminate any possible biases due to large numbers of new service requests associated with some disaster events. This paper also only considers a single measure of resilience. Zobel (2010, 2012) argued that a single measure cannot capture the resilience behavior of a system completely, and proposed expanding the characterization of resilience to include the system's robustness and recoverability as explicit sub-measures. Another extension of this research, therefore, could be to define robustness and recoverability measures in this current context and to evaluate municipal performance across different events with respect to these sub-measures. Finally, our analysis was limited only to the *Damaged Tree* complaint type, as received from all boroughs across New York City. Since the 311 dataset also includes the geographic location of service requests, another interesting extension would be to consider the relative performance of different boroughs of New York City, i.e. Manhattan, the Bronx, Queens, Brooklyn, and Staten Island, in dealing with disaster events.

ACKNOWLEDGMENTS

This research was supported by grants from the National Science Foundation (NSF-CRISP #1541155), the Global Forum on Urban and Regional Resilience, and the Institute for Critical Technology and Applied Science at Virginia Tech.

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Tracking in real time the blood products transportations to make good decisions

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ABSTRACT

The French Blood Establishment (EFS) is the only one in France allowed dealing with the blood supply chain. The EFS centers are scattered in France and blood products are transported over hundreds of kilometers, from collection sites to hubs and from the hubs to distribution sites. The strong constraints on lifetime and storage conditions imply a traceability of transportation steps very accurate, which is necessary in case of unexpected and unwanted events. To make "good" decisions, we propose in this research work to use the Physical Internet philosophy. Thanks to sensors in containers and Complex Event Processing modules to aggregate and filter the data collected, we would be able to create a real time "field model". In case of crisis this model would be helpful and perfectly adapted to help the crisis unit to make "good" decisions and maybe propose solutions based on the past events.

Keywords

Blood, Physical Internet, Complex Event Processing, Process Mining

INTRODUCTION

The French Blood Organization (EFS) is the only one in France allowed dealing with blood supply chain from the donor to the receiver. In order to respond to the hospitals and patients' needs (more than 1 million people treated with blood products each year) the EFS has to collect blood (or directly one of its components) from around 10 000 people every day. This whole blood is split in 3 components (platelets, red blood cells, plasma) and samples are tested to validate the innocuousness before distribution to patients. We won't describe in this paper the plasma and platelets donations processes. In fact, the transportation processes are almost identical to the whole blood ones. Moreover, the whole blood represents the highest number of donations.

Different blood types exist and they are often not compatible one to another. Hence, this organization has to take from donors, among the 10 000 daily donations, the most important diversity of whole blood everywhere in France. Knowing that between two donations of "whole blood" donors have to wait 8 weeks at least 560 000 regular donors would be required (8 weeks * 7 days * 10 000 donations per day). However, on the ground, donors do not come back every 8 weeks precisely to give their blood and their donation may be refused (medical issues, illness). As a result, 40 000 day collections are necessary everywhere in the country each year, changing the collection sites in order to attract the broadest part of people with enough blood diversity (groups and phenotypes). Each year, the EFS collects around 2.98 million pouches and samples from 1.65 million donors. For this reason, this establishment is scattered among French regions in 132 EFS centers to collect and distribute the validated blood products to any hospital. These "blood products supermarket" (called distribution centers) have to store enough blood products with a high diversity, ready to be delivered because we do not know a priori the blood characteristics of the receivers, except for planned surgery or treatments.

Because of strict storage conditions (different temperatures according to the products, from -25°C for plasma, to +22°C for platelets), some short lifetimes (5 days for the platelets) and traceability requirements, it is necessary to follow precisely each pouch during its lifecycle. In fact, a blood product may cross hundreds of kilometers between the donor and the receiver. Knowing the temperature and time constraints, the transportation requires location and temperature tracking of each product in real time in order to optimize the transportation and detect unsafe products before distributing them.

The EFS centers are scattered in France and the blood products are vital for thousands of people. As a consequence, any attack or massive accident and any climate incident (storm, flood, etc.) or traffic jam may affect the blood supply chain. Therefore a crisis situation has two effects on the transport of blood supply chain: (i) an unpredictable request of blood products is made in the area of the crisis situation, which could imply a break down of specific blood product and (ii) the roads used by the supply chain as to be modified in order to take into account the effects of the crisis (e.g. road closure, traffic jam, etc.).

Therefore the work presented in this paper aims to modify the supply chain in efficient way based on the information gather from the crisis situation. For this, the main contribution of this paper is the description of a case study and the description of our approach to achieve this objective. Thus this paper is divided in three parts. In a first part, we explain several concept and research works that could be used to improve the blood products traceability during transportation steps and the process robustness to incidents. In a second part we develop the EFS organization and transportation process. In a third part we discuss the advantages of such approach to in a crisis management.

SCIENTIFIC CONTRIBUTION

Due to the consequences on ill or injured patients, the EFS must be able to react quickly and efficiently to any crisis due to an unforeseen event that affects the blood product supply chain. Therefore our objective is to transform the supply chain into an agile supply chain able to react at least to these 3 kinds of requests:

1. Blood product instant rise in a hospital or an area (attack, massive accident)
2. Site closure or break down of specific blood devices (testing laboratory, blood irradiating device)
3. Modify the supply chain based on information of the crisis situation (road(s) closure, traffic jam, forest fire, flood)

As described below, the transportation is one of the most sensitive steps of the blood supply chain during which currently we are almost blind. However, in case of an unforeseen event, which launches a crisis, we have to react quickly and efficiently with enough reliable information to make a "good" decision.

Agility

In order to meet the needs implied by a crisis, any system has to be agile and adapt the response to the field. According to (Bénaben et al. 2015), agility can be considered as the ability to perform detection and adaptation to events (in a rapid and efficient manner). Agility may be considered as a way to adapt the dynamic of the situation and can be defined as follow (Barthe-Delanoë et al. 2013):

Agility = (Detection + Adaptation) * Reactivity

1. The detection is the finding of a situation gap that makes the ongoing business processes not relevant to the running situation,
2. The adaptation is executed, when a gap occurs, to change the current business processes to make them better relevant to the context,
3. The reactivity is a property that must ensure that detection and adaptation are done in a real-time (as fast as possible).

As a result, agility would permit to detect if the current transportation processes meet the requirements of the existing situation, which changes and evolves, and modify these processes if they are not yet relevant. The detection appears here as a key point to be able to adapt our way of doing in a crisis situation. During the blood product transportation processes we have to retrieve data from the field to have a real time model of the existing situation.

Physical Internet

Knowing this need of reliable information in real time, a Physical Internet (PI) approach could be helpful to reach this goal. As explained by (Crainic and Montreuil, 2016), the PI initiative is developing concrete means able to transform the fragmented freight transportation, logistics and distribution industries into an industry based on hyperconnected logistics. Goods will be encapsulated in designed-for-logistics standard, modular, smart and reusable PI-containers, from the size of small cases up to that of cargo containers (Crainic and Montreuil, 2016). These PI-containers should be routed across open logistics centers by exploiting real-time and worldwide identification and tracking systems. These containers can carry a number of data or information needed during the various operations related to transportation and handling (Charpentier et al. 2015).

Actually, a lot of existing research works focus on the supply chain improvements of such an approach. We think that these concepts could be used in order to improve the blood product supply chain and manage crisis more efficiently thanks to the amount of data collected from these containers. In fact, regarding to the number of blood products containers transported every day in France (several thousands) at any hour between dozens of EFS sites, the PI approach just for this organization would generate a huge quantity of data. These data concerning different events the PI-containers pass through, after being treated automatically would allow us to know the processes states with a high reliability and make a “good” decision.

Conceptually, the PI-containers can hold any product, like a traditional box but are active because they possess a component that owns several data linked with the shipment. (Sallez et al. 2015) distinguishes 3 types of PI-container:

- The T-container, like the actual one, it is directly transported by trucks, trains, boats, etc. In our case, the trolleys loaded in trucks are T-containers.
- The H-container, dedicated to be handled. It measures one of the several standard sizes, like the containers used currently at the EFS for fresh blood pouches or samples for instance.
- The P-container, it constitutes the packaging of each product, in our case this is the pouch.

The P-container sizes are adapted to the H-container dimensions, and that the same between H and T containers. These different sizes appear essential and well adapted to our need. In fact, if something unexpected happen which could have an impact on our products we need to know their location and storage conditions. If we track the H-containers (or T-containers), and know the list of the P-container they contain, knowing the location and storage condition of the H-container, we know location and storage condition of the P-containers and thus of our products. Thus, we would be able to follow each pouch in real time and warned in case of problem.

Complex Event Processing

The encapsulated containers’ sensors collect a huge amount of data (several thousands of container, data collected every X minutes) that has to be treated to model and describe the process state (see figure 1). For instance, Physical Internet containers will send data like “I am here, my speed is X and the temperature Y”. Each data alone does not enable to deduce anything and we do not know if this container is endangered. Similarly to (Villari et al., 2014), we would like to use lambda architecture to exploit PI approach for two purposes: a real time and a reactive analysis. First, thanks to a Transport Management System software we plan the trucks rounds, and every containers route.

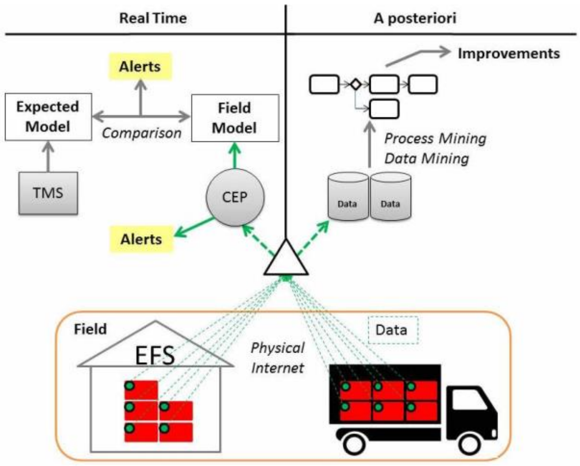

Figure 1. Lambda architecture for surveillance module

On the one hand, next to that, a complex event processing module aggregate, reduce and filter in real time all the data collected and sent by the sensors. We would be able to create alerts, based on specific and simple rules ("the temperature is lower than X"). At the same time we feed the "Field model". This model is compared with the expected one (provided by the TMS) and complex alerts are produced in case of divergence. This system would have two advantages:

1. Detect a crisis situation based on reliable information built with simple and complex rules
2. React properly in real time to a crisis situation, knowing a "Field model" fed in real time with data

In any case, it would be easier to make accurate and adapted decisions thanks to real facts measurements.

On the other hand, we will be able to rebuild our crisis management processes. Indeed, these data may be stored in databases. Data Mining and Process Mining on these huge log files, processed after the crisis, should be able to model the processes and find ways of improvement if any similar case occurs in the future. The Process Mining approach we use here is described by (Van der Aalst, 2011). Combining data and defining rules "If the container was here at this temperature this event occurred" we define the state of each container all along the time and the process step they went through. These analyses after crisis would be helpful to react faster and better if the same root events occur. Alerts on these particular events could be generated and allow the EFS to be aware that an unwanted situation is about to happen with a high probability.

BLOOD PRODUCTS AND SUPPLY CHAIN DESCRIPTION

The Blood supply chain

The EFS is split in 15 "regions" in France. Each of them owns its regional departments (collection, preparation, distribution, technic, logistic, communication, etc.). These departments apply in their perimeter the national strategic decisions and participate to national projects about their field.

We count 132 sites in France. In general, a region is made up of three types of sites:

- A hub composed by the preparation and usually the administrative and support departments.
- Several sites located throughout this region (from 5 to 15 approximately). In the majority of these sites a collection and a distribution centre are located. From these sites "one day collection teams" may leave to collect blood in near towns, universities, etc.
- In 4 regions, there is a laboratory, named QBD, in which we test the samples of every blood donations. Anywhere a person gives his blood the samples linked to the pouch will be treated in one of the 4 QBD.

Figure 2 represents those sites in a region and the main labile blood products flows between them.

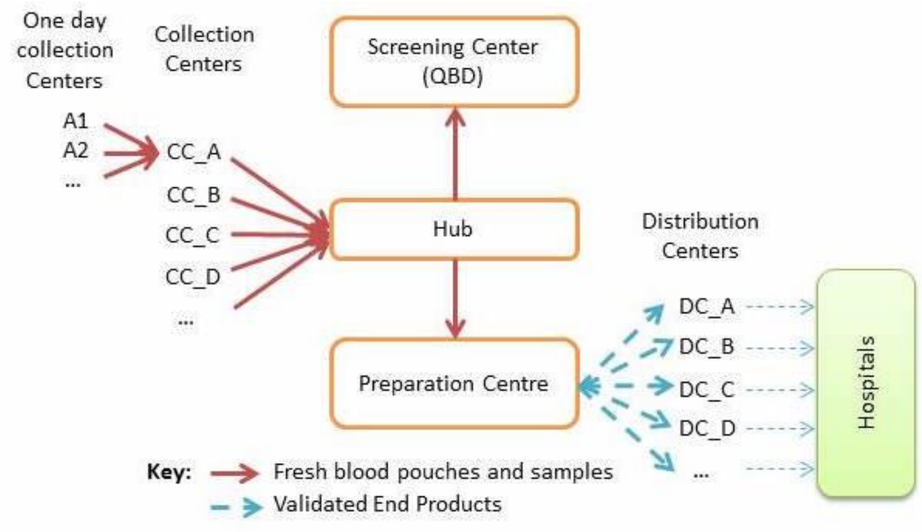

Figure 2. Labile blood products flow between collection and distribution centers

The supplying blood products

In order to meet the labile blood products' needs, the EFS follows an accurate process between the donors and the receivers (cf. figure 1):

1. A donor gives his whole blood in a collection centre. This collection centre may be in an EFS site or in a one day collection site (truck and/or tents, spaces lent by firms, universities…) that comes back to the nearest EFS permanent centre at the end of the day. A 500ml pouch and 6 blood tubes are collected from each donor.
2. All the donations (pouch and sample tubes) of the day are gathered in the EFS site and put in transportation container. A carrier, on a planned round, comes at one specific moment of the day and carries these boxes to the preparation platform, usually located in the regional hub.
3. In this site, each pouch will be treated and its components separated in three end products: plasma, platelets, and red blood cells. The day after at about midday these products are ready to be delivered if the samples do not reveal an illness. In some occasions, the product has to be irradiated before being distributed to a fragile patient. This need usually implies an extra transportation step to reach the irradiating device (quite rare and expensive) the closest.
4. In the meantime the sample tubes of all the collection centres of the region are gathered in this hub and carried to the QBD which is usually located in another site and another region (4 QBD in France vs 15 regions). In this lab, the samples are tested to confirm that the labile blood products are healthy and we are allowed to deliver them to patients.
5. If the results of its samples are correct, each labile blood product (plasma, platelets, red blood cells) must be stored in a central warehouse or in one of the regional offset stock (distribution sites). When a hospital needs a product, as a matter of urgency or for a scheduled surgery, a nurse calls the blood distribution site the nearest, asks for a product and call a carrier to pick it up. If this EFS centre owns this blood product it delivers it. However, if this EFS centre does not own it, we ask for an urgent transport between this centre and the closest one which owns it.

These regional and inter-regional transports are most of the time regular. Trucks rounds are planned to pick up blood donations and distribute end products to each collection/distribution site every day.

Lifetime and Storage conditions of blood products

The blood supply chain is very sensitive to any unwanted event because of:

- Product diversity: There are several dozens of blood products types (groups and phenotypes), which are often not compatible one to another. Consequently, it is necessary to take blood from different donors and store the most important diversity of blood products the closest to the future needs. To achieve this need, the EFS must be located in many decentralized centers in France which means to may be concerned by any traffic or weather issue in France.

- Compatibility: An inappropriate product may be lethal to a patient. Thus, it is essential to own and find in the blood products stock the appropriate one. Thus, each pouch can be asked anywhere. In case of accident or attack, we might have to find and transport as a matter of urgency over hundreds kilometers the only pouches compatible with a patient injured.
- Storage conditions: The blood products, as described below, must be stored in appropriate temperature environments and some of their lifespan are short between the donation and the transfusion (5 days for the platelets). Blood products are critical and have to be treated carefully all their "life" along, either in a site or a vehicle.

We can consider that each site in a region is 50-100km distant from the others. We distinguish 3 main transports. It is important to understand that in a same vehicle containers of each step may be gathered:

1. From the collection centres to the hub (raw materials: whole blood pouches)
2. From the hub to the QBD (samples of the raw materials)
3. From the hub to the distribution centres (blood products validated: platelets, plasma, red blood cells)

We focus here on the storage conditions. The table 1 sums up the constraints:

Table 1. Labile blood products storage conditions

Products	Lifetime	Temperature
Whole blood	Less than 48h	20°C or 4°C
Blood samples	Less than 48h	4°C
Platelets	5 days	22°C shaken
Red blood cells	42 days	4°C
Plasma	1 year	-25°C

Considering the very short platelets lifetime, the gap between storage temperatures and their level which have to be respected during the transport, this process appears as one of the critical step of the supplying labile blood products. Moreover, if we need to deflect a vehicle to supply as a matter of urgency a site with blood products for instance, it may impact fresh blood pouches in this vehicle which need to be treated quickly. Thus, making a decision without knowing in real time, anywhere at any time, the cargo and the state of any vehicle which transport blood products appears difficult.

Traceability and problematic

Currently, paper documents insure the containers (and product they contain) traceability. When a laboratory worker stores in a shipment area 3 containers, he fills in a paper form with different information: his identity, the recipient identity, the current site and the destination site, the containers quantity and their storage temperatures, the date and time. When he takes in charge these boxes, the carrier fills in the same document with his identity, the date and time, and the consistency check of the packages he takes. He leaves a copy of this document on the sender site which notifies his act and shows the evolution in the transportation process of this container. Thanks to temperature sensors in the refrigerated enclosures in the vehicles or into the isotherm containers, we have data about the temperature all along the transport. These data are usually visible in real time by the carrier on his dashboard and by the users (sender or recipient) when all the containers are unloaded.

In case of emergency, this system is not efficient and do not allow to make a "good" decision with enough reliable information. In fact, unless we look at every paper form on each site of the region to know which are the products in the containers in the vehicle we do not have a reliable visibility on what each vehicle transport, either in quantity or quality. In our Warehouse Management System a product may have one of these two states: "In site A stock" or "Sent from site A to site B" but nothing more. As a consequence, the traceability is insured but on different media (papers on sites, temperature in the truck or on a web application, planned round, product in our WMS, etc.) and different places. The sources of exploitable data are numerous, a lot of them are not computerized and there is a lack of some data.

In case of crisis (unexpected demand of a hospital, round vehicle incident (traffic, bad weather conditions, issue with the temperature of an enclosure, etc.), truck overloaded, etc.) we do not have enough information to make a good, or the less worst, decision. The monitoring and the tracking of these sensitive product are not effective and neither efficient.

APPLICATION CASE

We described now 3 kind of crisis that can occur anytime in the EFS:

1. Blood product instant rise in a hospital or an area (attack, massive accident)
2. Traffic jam or bad weather conditions
3. Breaking down of an irradiating device.

In particular those last years and maybe future, France has to deal with terrorism threat. Charlie Hebdo attack, November 2015 Paris attacks, July 2016 Nice attack are one of the last and most deadly terrorist attacks in France. In this situation, or after a major accident (car crash, explosion, building collapse, etc.), the blood needs in the nearest hospital usually rise quickly because of all the people injured. A crisis unit is ready to be opened whenever and the transportation of blood must not be a problem.

If a rise of blood product needs appears in a medium size city, in which an EFS center named “A” is settled, the center will receive all the demands from the nearest hospitals. Usually, in this kind of situation, people are transported in different hospitals, sometimes in several cities in the region, which implies several blood products demands to several EFS centers. As a consequence, the EFS centers that have been asked for products will try to deliver them. In this region, like in every other, emergency transportation processes, containers, transport subcontractors and EFS carriers are defined and ready to be called at any time.

Because the demand is high and diverse, the EFS center “A” may not have all the blood products in its warehouse and even if this center is able to deliver them all, it has to resupply its warehouse as quick as possible. In this situation, the central warehouse in the regional hub site is usually asked to resupply the EFS center “A”. If some products are required as a matter of urgency to be delivered, the closest EFS center of the region, which owns them, must send some of them. In any case, resupplying or distinctive product need, the crisis unit may ask for help to other EFS region and transport blood product as a matter of urgency over hundreds of kilometers. It is not rare and implies a perfect coordination of all this flows between people who are often not located in the same places.

The numerous source of information are here inefficient. In fact, people who coordinate these actions do not know easily in real time where the vehicles they ask for are located neither if the storage temperature is respected and which the products in the vehicles are. Sometimes information from location and temperature sensors is available in real time but in different media that is complex in particular when several region have to provide site “A”. In some occasion, it could be faster to deflect a vehicle, which passes near from this site, but we do not know which the blood products it transports are. If a vehicle comes from another region, it will sometimes deliver the regional hub because of contract conditions. Then another vehicle will transport the blood products to site “A” in the region. In this situation, following and coordinating efficiently in real time the transportation with our current system is almost impossible. Finally, when the carrier arrives near the EFS site, he has to know if there is traffic jam, security perimeter and areas closed because of the attack, to adapt his way. Sometimes a police escorts may be necessary and have to be foreseen. Thanks to the approach we described before we could make decision thanks to a high number of reliable information about our container and adapt in real time vehicle ways to the needs.

The second example is about bad weather conditions and traffic jam. We described the EFS centers network above and noticed that any bad weather condition in France, which has an impact on traffic, may have an impact on the blood supply chain. A typical case is the wildfire or a flood, which create a road closure and traffic jam. Thanks to the real time system we described, it would be easy to know at any time if the products in the round vehicle are required as a matter of urgency on a site, if their storage conditions are threatened and make a decision: deflect the vehicle, make it wait on the departure site, ask for police escort, going back to the last EFS center, etc.

The third example shows how we could optimize easily the transportation in case of problem and save time. In fact, some products need to be treated in an irradiating device before being delivered to patients. This kind of device is very expensive and each region owns at least one, usually located close to the central warehouse. If an irradiating device breaks down, we need to organize transportations to the nearest one, sometimes in another region. Using existing rounds or deflecting a vehicle that contains the blood product we need to irradiate could permit not just to look for an available product in the warehouses of the EFS centers but anywhere around the closest irradiating device, including in the vehicles.

CONCLUSION

To conclude, we described the French Blood Establishment supply chain and the sensitiveness of the products transported. Currently, the traceability is insured but the meanings to achieve these goals are not effective and efficient enough to make good decision in case of crisis. Indeed, the numerous media on which data are registered, and for a large part not computerized, do not allow to the crisis unit or the transportation department director to have enough reliable, accurate and updated information. In order to collect and send data, the use of PI-containers appears adapted. Due to their sensitiveness and their vital impact, tracking (location and temperature) each pouch whatever are the conditions (rounds, emergency transportation) would be a real improvement. The lambda architecture, linked with Complex Invent Processing modules would generate with these data enough useful information to be alerted in case of problem, to make adapted decisions in real time and adjust after the crisis the response processes.

After some iterations, we expect to have enough data and relevant scenario to foreseen a crisis. Indeed, root events apparently not dangerous alone can have a very bad impact if they occur in a specific sequence. If we are able to spot these sequences it is possible to predict a crisis and propose solutions to avoid it or reduce its consequences.

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Constructing Synthetic Social Media Stimuli for an Emergency Preparedness Functional Exercise

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ABSTRACT

This paper details the creation of a massive (over 32,000 messages) artificially constructed 'Twitter' microblog stream for a regional emergency preparedness functional exercise. By combining microblog conversion, manual production, and a control set, we created a web-based information stream providing valid, misleading, and irrelevant information to public information officers (PIOs) representing hospitals, fire departments, the local Red Cross, and city and county government officials. Addressing the challenges in constructing this corpus constitutes an important step in providing experimental evidence that complements observational study, necessary for designing effective social media tools for the emergency response setting. Preliminary results in the context of an emergency preparedness exercise suggest how social media can participate in the work practice of a PIO concerning the assessment of the disaster and the dissemination of information within the emergency response organization and to the public.

Keywords

Social media, emergency preparedness, synthetic microblog corpus, disaster response training.

INTRODUCTION & RELATED WORK

Social media has the potential to assist in the management of regional disasters as observed during several events in the last decade (e.g., a terrorist bombing or a natural event such as a tornado, forest fire, hurricane, or earthquake) (Imran et al., 2015; Simon et al., 2015; Purohit et al., 2014; Imran et al., 2013; Card et al., 2013; Cassa et al., 2013; Blanchard et al., 2012; Cameron et al., 2012; Sarcevic et al., 2012; Vieweg, et al., 2010; Starbird and

Stamberger, 2010; Palen et al., 2010; Palen and Liu, 2007). With respect to assessing the scope of disaster, social media provide a platform for citizen sensing (Sheth, 2009) that may inform emergency command centers about ground events (Vieweg et al., 2010), the changing availability and need for resources (Purohit et al., 2014; Sarcevic et al., 2012), and changing public perception of events (Cassa et al., 2013). With respect to the dissemination of information, social media can also be a means for communicating with the larger public (e.g., to alert the public to evolving risks; to instruct the public about appropriate responses and available resources; to correct rumors; to solicit or disseminate information, or to match needs with offers of resources) (Cassa et al., 2013; DHS S&T Virtual Social Media Working Group and First Responders Group, 2014; Purohit et al., 2013). Thus, social media based exchange between the informal (citizen) and formal (professional) communities may facilitate effective crisis management.

Despite this potential for citizen roles, and despite recent initiatives by the formal response community such as the U.S. Federal Emergency Management Agency (FEMA, 2012a), few experimental studies address the utility of social media for formal response organizations, especially for assisting preparedness. This paper will report on our experiences in developing a social media component for a functional training exercise for a local emergency in a medium-size city in the Midwestern United States. It involved hospitals, county public health departments, city government, fire departments, police departments, and the regional Red Cross. Certainly, any effort to deploy a social media tool in a high consequence setting requires extensive testing, ideally conducted with the fidelity of a training exercise (Hughes, 2014). However, the examination of social media usage in a training exercise is more than practical necessity. While we are strong proponents of naturalistic observation in a real work setting, exclusively observational study presents several threats to scientific study that are mitigated in an exercise. For example, because an exercise is designed, we had access to ground truth. Second, deployment during an exercise allows us to control presentation parameters that could interact with the usage of social media, and/or are easily remediated with specialized technology. For example, we were able to control the message stream, and therefore knew the distribution of its contents and the rate of presentation. Known threats to usability such as data overload and low signal-to-noise ratio can be addressed with technology (e.g., Twitris (Sheth et al., 2014)), and therefore, can be reduced while we examine best-case utility. However, the study of behavior in a controlled setting is only as good as the design of the setting. The focus of this paper is on the design of the social media stream synchronized with designed exercise content. We also describe the standalone tool to control the distribution of messages to exercise participants and the way social media contributed to the assessment of the disaster and the dissemination of information, both within the responding organizations and between the responding organizations and the public.

EXERCISE DESIGN

The seven distinct types of emergency management exercises range from seminar to full-scale simulation (FEMA, 2012b). We conducted the current work in the context of a 'functional exercise.' This is the second most complex (and realistic) operations-based exercise just short of the full-scale exercise. Functional exercises specifically aim to assess the current response plans and to evaluate regional decision-making processes associated with implementing the plans. Thus, the local (e.g., hospital information centers, fire departments) and region-wide (e.g., Red Cross)

response agencies actively participated. However, the actual deployment of 'boots on the ground' (e.g., doctors, nurses, fire units, etc.) was simulated.

The scenario included two separate radiological attacks by a terrorist group. The first attack involved low level radiation distributed through the ventilation system at a large concert for children on Friday evening (the night before the exercise). The second attack was a radiological explosion (dirty bomb) at a large international convention on Saturday morning. This attack involved hundreds of injuries/fatalities in the explosion as well as widespread exposure to potentially lethal levels of radiation. Designed to encompass roughly three and a half hours, the scenario began early Saturday morning when radiation detection alarms go off at two different local hospitals (approximately 7:55 a.m.). The people triggering the "portal alarms" had attended the Friday evening concert and were coming to emergency rooms due to illness or injuries that were unrelated to the radiation events. Standard protocol is for the patient who sets off these alarms to be escorted from the emergency room and returned to the hospital through an alternative route to avoid potential contamination of the emergency room. This high degree of uncertainty about the source of the radiation tested coordination across hospitals. Shortly thereafter (approx. 8:10 a.m.) the dirty bomb explodes, testing medical surge and mass casualty response. As the scenario created uncertainty about the sources of radiation and the potential lethality of the radiation by design, a clear potential for confusion and public panic resulted. Thus, the exercise represented an ideal context for using social media to simulate the public confusion in a real disaster.

SYNTHETIC MICROBLOG STREAM CONTENT

We employed a Twitter-like system of microblogs. Each message entry followed the typical format of a 140character (maximum) microblog, and included an indication of the sender, message content, and hashtags to group messages thematically. Each microblog also had a visibility attribute, set to *high*, *medium* or *low* by the research team. This controlled the proliferation of microblogs throughout the exercise, and reflected either sender influence or context relevance. We designed the software to randomly select usernames from an extensive list of real Twitter users for each artificially generated message. Users could click these names in the interface that would then hyperlink to corresponding Twitter profiles in a new window. For the actual scenario participant, the link directed to his or her organizational profile.

The microblog stream of tweets consisted of three distinct sources:
1) *Background set*: the real-time stream of microblogs unrelated to the event by actual Twitter users in the region (background noise);
2) *Authoritative set*: those entered at the user interface by PIOs and simulation coordinators, and their 'retweets' (forwarded tweets) generated by the system; and 3) *Constructed set*:
3a) *MSEL specific constructions*: those generated by the system as required for the MSEL (Master Scenario Event List);
3b) *Generic emergency related constructions*: specified by parameterized microblog templates for categories such as 'Angry Rant'.

Table 1 lists the semantic categories that we used to generate specific microblogs. These categories reflect both content developed in the exercise planning process and general content reflecting the analysis of previous actual emergencies. In particular, we considered two major events of 2013: the Boston Marathon bombing (Cassa et al., 2013) and the Westgate Mall attack (Card et al., 2013). Prior studies of these events provide examples of real microblogs on Twitter and categories of content discussed in the aftermath of these events. While both incidents were important in shaping our understanding of message categories, the Boston Marathon bombing provided a more directly compatible dataset, as our simulation scenario also involved the bombing of a metropolitan American city during a large gathering of international participants. We sampled a set of 2,567 tweets originating from the state of Massachusetts in about 2.5 hours after the bombing took place, from the Twitter data set collected via Twitris (Sheth et al. 2014). Twitris constantly collected the filtered stream of English language tweets from the Twitter Streaming API for event-related keywords and hashtags (e.g., "#bostonbomb", "boston bomb", "boston marathon").

Table 1. Semantic Categories for Scenario-Relevant Microblogs. Notation Reflects the Distribution in our Corpus

Angry rant T=149, L=85, M=64	Distant Observer T= 426, H=426	Panic over exposure T=18, L=18
Appeal for help T=71, M=71	Fear for children * 113 T=113, H=62, M=32, L=19	Parent who set off alarm T=131, L=131
Breaking news – explosion T=585, H=426, M=73, L=86	General discussion T=492, H=281, M=141, L=70	Prayer T=93, L=93
Breaking news - status update T=72, M=72	Ham operators with nowhere to go T=88, H=40, M=48	Public reaction T=31, L=31
Call for calm/patience T=63, H=43, M=20	Informational T=190, H=190	Revision of all-clear T=120, H=60, M=60
Call for help T=40, M=40	Injured T=114, M=71, L=43	RRR TWEET * 182 T=180, L=182
Caution and Advice T=78, M=60, L=18	JohnQPublic T=140, H=140	Rumor/ False information T=130, M=130
Confusing public reaction on reports T=50, L=50	Media help resources T=25, M=25	Status update - radiation T=905, H=905
Confusion of Hara/Hobart T=96, H=64, M=32	Media report T=175, H=122, M=53	Sympathy T=40, M=40

Confusion of TC-99(m) T=30, M=30	Non-immediate witness T=255, H=141, M=71, L=43	Uninjured present T=43, L=43
Correct information/treatment T=66, M=66	Non-immediate witness, uninformed T=71, H=141, M=71, L=43	Uninjured, injured friend T=43, L=43
Corroboration * 213 T=213, M=168, L=50	Observers in ER waiting room T= 514, M=320, L=194	What do I do? T=183, H=62, M=102, L=18
Criticism T=80, M=80	Offer to help T=58, M=58	Where to go? T=144, H=60, M=66, L=18
Dayton Region T=828, M=828	Official announcement T=240, H=240	Worried about exposure T=505, H=161, M=245, L=99

Note. T = Total Tweets, H=High visibility, M=Medium visibility, L=Low visibility where T=H+M+L.

Background Set

To simulate the background noise (microblogs unrelated to the emergency events) we collected tweets from the local (Dayton) region over a four-day window before the exercise day that included no particularly noteworthy events (i.e., no major elections, sporting events, conferences, etc.). We used the Twitter Streaming API's public "statuses / filter" (Twitter Inc., 2014) method to obtain tweets from the specific region of the exercise using a bounding box defined by a pair of latitude and longitude for the two points on the geographical map of the region: south-west and north-east. Visibility for the background set was low. The background set comprised approximately 76% of the microblog stream.

Authoritative Set

We also had the capability to generate additional microblogs in real time during the exercise, manually specifying the relative visibility of each message as high, medium, or low, corresponding to the visibility levels we assigned to each PIO account based on ranking of their real-world followerships on Twitter. These messages appeared in the unfiltered social media feed without distinction and were 'retweeted' by ghost accounts, the frequency and duration of which determined by their relative visibility setting, set at the time of creation based on a subjective conjecture about how popular a post of that type would be.

Constructed Set: MSEL Specific Constructions

Scenario specific microblogs included the following examples.

> Example 1: patient at *[hospital]* just kicked out after testing positive for radiation… WTF!?!
>
> Example 2: They just kicked some guy out of the ER for radiation poisoning #HulkingOut
>
> Example 3: Do hospitals not treat radiation poisoning? Am I in trouble?

These microblogs simulated witnesses in the emergency room, who sent these when someone who had been at the concert on the previous evening tripped the radiation detection alarms. Because the witnesses are not privy to hospital protocol for rerouting such cases, they infer that a patient is being denied service at that hospital due to radiation. Also included (see Example 2) is a hashtag that ran throughout the simulation at various points. This one demonstrates contradictory levity that appears in real tweet streams. These examples deliberately indicate a lack of understanding on the part of the public, the correction of which falls within the bailiwick of public information officers (PIOs). Visibility for these messages depended upon designed ground truth. True events were set to high, and others as required by the exercise for the relevant semantic category of the event (see Table 1).

Constructed Set: Generic Emergency-Related Constructions

In addition to specific microblogs that were tied to specific scenario events, we added microblogs based on observations of Twitter streams taken from actual emergency events. Initially, we attempted to directly transform observed tweets to the exercise scenario by using string-based transformation rules. Obvious examples (e.g., #bostonbombing became #daytonbombing) presented little trouble, but the depth of contextualization made a complete transformation both prohibitively difficult and occasionally erroneous. For example, discussions of the marathon could have related terms like runners and mile markers (and permutations). We concluded that the extensive details of the context precluded this approach. Instead of this direct transformation, we opted for a thematic translation of the events. Looking at the messages and the type of categories observed in prior studies

(Cassa et al., 2013; Card et al., 2013), we created templates of microblogs. Some we made by transforming items within tweets from Boston (see Example 4). For others, we adapted themes to the specific context of our simulation (see Example 5). We then varied the options in parentheses to create a set of functionally similar but identifiably distinct microblogs. In Example 5, the two alternatives in two places (denoted by forward slashes and parentheses, respectively) yielded four possibilities to create a computationally inexpensive diversity:

> Example 4: RT @the123abc: It should be noted that if you suffer from #PTSD, limit your exposure to the **(#daytonbomb / #radiation)** coverage. Social media can b overwhelming.

> Example 5: **(#bananasplits / #hobartarena) (We enjoyed with kids / kids loved)** the concert at Hobart last night

Visibility depended upon the relevance of the semantic category of microblog content for the MSEL timeline. Because we were also part of the exercise design team and had access to ground truth, we had knowledge of relevance. In Example 4, we set visibility to 'medium' given that it was related to the "caution and advice" category, and inherited from the transformation of a Boston bombing related tweet set.

INTEGRATION OF MICROBLOG CONTENTS SOURCES

We integrated the scenario-related microblogs and background noise to create a corpus of over 32,000 microblogs. We then synchronized the timing of scenario-related microblogs with the MSEL for the exercise. During the exercise the microblogs streamed at a rate of approximately two per second via the interface shown in Figure 1.

The scheduling of the frequency and volume of microblog contents was designed to reflect the specified visibility level for individual microblogs. The fact that the number of microblogs from the background set and the authoritative set and subsequent 'retweets' was unknown prior to the start of the simulation presented an integration challenge. To address this challenge, our primary scheduling heuristic made use of the values generated by a realtime trending topics function from Twitris system (Sheth et al., 2014) in the overall data stream at each timestamp 't', throughout the simulation. We considered the count of microblogs mentioning the topmost trending topic (within the current sliding window of past K minutes the timestamp 't') to be the current baseline for high visibility, from which the values for medium and low visibility were proportionally derived. We defined medium visibility as one half of the value of high visibility, and low visibility was one third of value for high visibility. This final count was used as the volume of microblogs scheduled to appear at random intervals throughout the next five-minute window, starting from the entry time of the initial template microblogs from the Constructed Set. These fractional values gave us the desired effect of topics mentioned in a high visibility microblog template or PIO user microblog, to appear at or near the top of a list of the top 20 trending topics. Those from a medium visibility microblog template probably (but not necessarily) appeared somewhere within the list, and those from a low visibility microblog template probably not (but still possibly) appearing in the list.

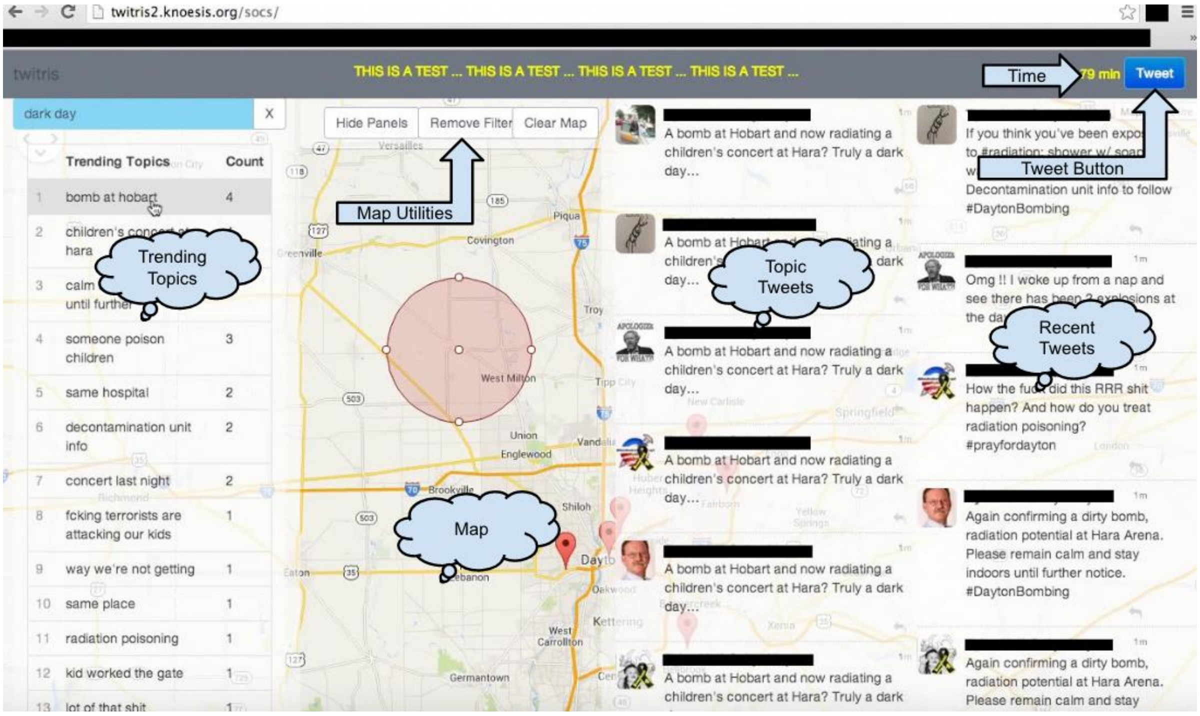

Figure 1. Snapshot of Twitris-Based PIO Interface to View the Simulated Microblog Stream during the Exercise.

INSIGHTS FROM EXERCISE DEPLOYMENT

We reviewed the screen capture of one active and visible PIO to examine a detailed account of his use of social media. Evidence for engagement occurs in the form of intentional cursor movement, associated with a change in the appearance of the display. This includes selecting trending topics, scrolling the microblog stream to review previous content, and highlighting microblog stream contents. It also includes using the cursor to point at individual microblogs, presumably to keep place while reading. Throughout the exercise, and despite some interface bugs, the recorded PIO was nearly completely engaged in the social media tool with more than three cursor displacements per minute. This metric underestimates engagement, as we did not count multiple movements within the same episode separately (e.g., scrolling the microblog stream back and forth several times without stopping). We note the exploitation of several different functions of the PIO interface in the following sections.

Information Monitoring

The PIO identified microblogs in the unfiltered stream concerning radiation poisoning less than a minute after the first related microblogs appeared. The PIO also identified microblogs in the unfiltered list concerning the dirty bomb, approximately 1'30" after the first related microblog appeared, and almost a minute after the topic first appeared midway in trending topics. Once he detected the event in the unfiltered stream he returned to trending topics and selected a related topic at the top of the list. Both episodes illustrate a reliance on the unfiltered stream for initial detection, and suggest concern for the reliability of the filtering function. Comments in the followup survey include his interest in knowing more about how the filtering function works. Nevertheless, the PIO used trending topics to identify the existence of a video of the bombing from the trending topics. He later investigated the hashtag identifier of the potentially responsible group, which did not appear in trending topics. He also relied on trending topics to detect public concern once the name of the radioactive agent was released. Late in the session, once focused on a citizen microblog, the PIO pursued the URL link it contained.

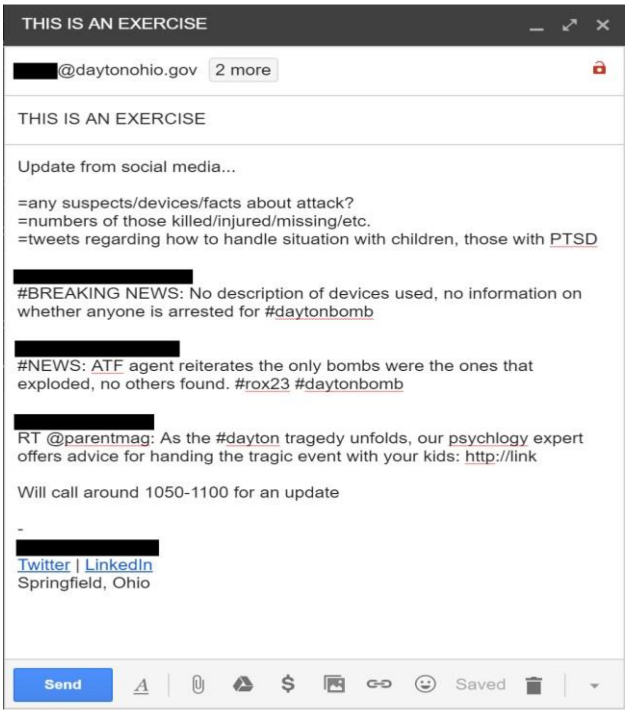

Figure 2. Email Written by the Central PIO to Fire Department Officials Requesting Information

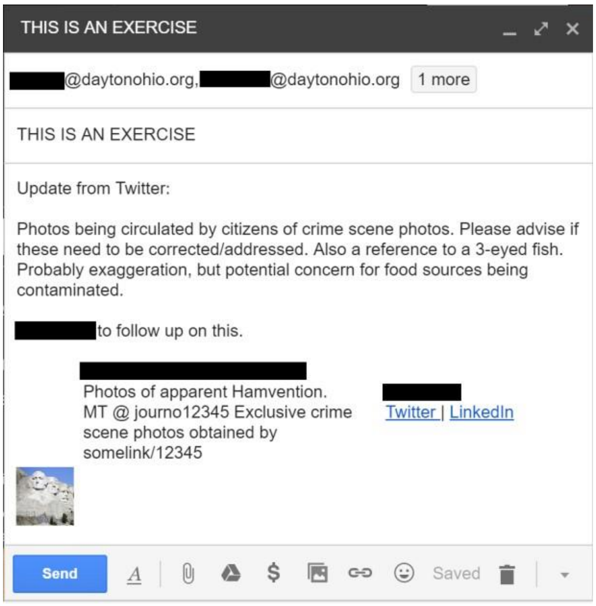

Figure 3. Email Written by the Central PIO to Fire Department Officials Offering Links to Pictures

Information Distribution

The central PIO functioned as a filter on the social media stream, distributing contents via microblogging, e-mail and telephone. The persisting microblogs allowed the PIO to copy microblogs and forward them via e-mail to interested parties including the fire department and the police (see Figure 2). He used this to identify public perception and even provide crime scene photos (see Figure 3). The separate trending topic microblog list allowed the PIO to copy several examples in one step, as opposed to copying individual examples from the more rapidly scrolling unfiltered stream. Nevertheless, no member of the formal response community responded to the PIOs bulletins using e-mail. The PIO also made numerous calls related to the Twitter stream to the fire command center. The function of these calls was typically to check the validity of information gleaned from the social media feed, or at least to make the fire department aware of trending topics he felt merited attention or followup. An advantage of the telephone medium is a confirmation of receipt, absent in the one-way email attempts noted above.

Information source

The tool provides two functions for examining the source of information: the map and the link to user profiles. Early on, before the dirty bomb and with a preponderance of noise, the PIO manipulated the map field of view, and frequently cleared the push pins. He also used the user profiles to examine the background of the sources before sending microblogs and evidence via e-mail.

CONCLUSIONS

The primary technical contribution of this work is the creation of a synthetic social media stream, fulfilling two requirements of applied research. First, the synthetic stream embodies an explicit, testable model of social media content. Second, the synthetic environment supports response preparation activities. Third, a synthetic stream (with known properties) is required to support the controlled testing of social media tools for emergency response. This allows researchers to separate out properties of the scenario, the social media stream, and the tool in assessing behavioral responses. Compared to the natural environment, training exercises offer control over the difference between critical variable (signal) and extraneous, uncontrolled confounds (noise). In addition, exercises make possible the recording of data and context relatively easily, as well as access to an a priori ground truth. With a relatively modest social media tool we have demonstrated a capability to exploit social media in emergency response. The full value requires continuing investigation of social media search heuristics (e.g., Hampton & Shalin, in press) to filter the content of social media. When such information processing tools are available, they will change work practice regarding both the gathering and dissemination of information critical to effective emergency response.

ACKNOWLEDGEMENTS

We acknowledge partial support from the National Science Foundation (NSF) awards: SoCS IIS-1111182: Social Media Enhanced Organizational Sensemaking in Emergency Response; EAR 1520870: Hazard SEES: Social and Physical Sensing Enabled Decision Support for Disaster Management and Response, and IIP 1542911 PFI: AIR - TT: Market Driven Innovations and Scaling up of Twitris- A System for Collective Social Intelligence.

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Command and control studies

The Role of Artefacts in Creating a Common Operational Picture During Large Crises

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ABSTRACT

This paper is about the work that takes place during large police operations in different command post settings, and how artefacts are used in the collaborative process in creating a common operational picture (COP). We apply “artefactual multiplicity” as our analytical lens. An interpretative research approach has been applied in form of ethnographical field studies using observation and informal interviews as data collection techniques. The artefacts that have been studied are definable as common artefacts, i.e. artefacts that are commonly available in our work environment. Based upon the five separate studies, the artefacts studied are found to be very important as collaborative tools and many also have embedded visualization functionalities. The main contribution from this research is 1) extensive knowledge about how the artefacts are used in the establishment of the COP during large police operations, where the process of establishing the COP is, to a very large extent, dependent upon the artefacts’ collaborative and multiple functions; 2) the proposal and suggestion to study the whole staff and the artefacts used by the staff as one heterogeneous unit, as a record of activities. Studies of single artefacts in isolation reduce the possibility of seeing the full multiplicity of all the artefacts used within the staff, and the complexity of the intertwined web of artefactual functions.

Artefactual multiplity, Artefacts, Common operational picture, Temporal command setting, Police operations, Staff

INTRODUCTION

This paper aims to contribute a better understanding of the complex work environment in which a collaborating group of emergency response actors establish a common operational picture (COP) in emergency command centers during extraordinary events. The establishment of a COP is one important aim during large police operations, and the COP “is created by an actor and consists of a selection of important parts of the available information, in form of descriptions and predictions of what is going on, and related information as e.g. resources, actions, prognosis, and perceptions” (Translated from Swedish from Borglund et al., 2014). To a successfully manage a large crisis or extraordinary event it is necessary to attain a common understanding of what is going on (Nylén, 2006; Svensson, 2007). The COP should be seen as an important basis for an organization’s capacity to meet the challenges brought by a larger crisis or extraordinary event (Borglund et al., 2014), and to reach what Harrald (2006) defines as “agility” i.e. the capacity an organization has to move quickly and adapt to new situations during extreme events. From a more operational aspect the COP aims to help the commander in charge to make better decisions and to help the authorities involved to balance their efforts in relation to the actual situation.

The focus in this paper is on the creation of the common operational picture (COP) that is established during large police operations (extraordinary events) in which the police organize themselves in a *staff*. The staff is a temporal, intermittently activated command construct, that must be separated from the more permanent kind of staff organizations that exist and are running more permanently as e.g. joint of staff. From now on, when the term *staff* is used in this article it refers to these temporal, intermittently activated command constructs. In the set of rules and regulations for the Swedish Police on how to manage situations that are out of the ordinary, there are instructions on how to set up the staff. In the same instructions, cooperation is described and stated as being a central component for successful management of large police operations (Nylén, 2006).

In academic outlets and databases, it is difficult to find research on these kinds of temporal organizations focusing on the Police or other organizations involved in crisis management. The temporal organizations studied in this research have similarities with project organizations see e.g. (Lundin and Söderholm, 1995). CSCW (Computer Supported Cooperative Work) and CHI (Computer Human Interaction) articles found involved studies in more traditional control rooms, or dispatch centres, such as the Swedish National Emergency Centre (Pettersson et al., 2004), control rooms in London's underground (Heath and Luff, 1992), urban traffic control (Filippi and Theureau, 1993), in command and control rooms (Luff and Heath, 2000). These studies all focus on permanent organizational constructs, and not on the temporal organizational construct of the staff, which is the focus in this paper.

The COP should be achieved and shared through cooperation among actors within the police (Nylén, 2006). Nylén's manual (2006) suggests artefacts should be used to make management of the crisis and establishment of a COP easy. However, the manual does not say how this should be done. Departing from, and inspired by the concept of Socially Embedded Technologies (SET) the *aim of this paper is to increase knowledge about the role played by artefacts found in the staff during large police operations, and how they are used in the collaborative work process of establishing a COP*. The concept of artefactual multiplicity (Bjørn and Hertzum, 2011) will be used as an analytical lens to better understand how the creation of COP is established in a staff setting. This will facilitate study of the interaction between the heterogeneous artefacts found in a staff context and the actors participating in the creation of a COP. SET is an approach that springs from the CSCW community and "is based upon the fundamental assumption that we need new ways to conceptualize research on design, which takes into account peoples' social practices without limiting the human interaction to an individual computer-user relation." (Bjørn and Boulus-Rødje, 2015, p. 341). The long-term goal of this research is to be better able to design technology supporting the collaborative and complex work taking place in similar temporal organizational constructs as the staff. This research, with its rich empirical material encompassing 5 separate studies, contributes with new design implications and insights in this domain, and should bee seen as contribution to other stated normative research contributions in which very limited empirical data have been used (e.g. Turoff et al., 2004).

This paper is structured as follows: first we further present COP, and the theoretical lens applied. Second, we present the research approach and the research method applied, a presentation about the construct of staff within the police and the artefacts one could expect to find there. Third, the results are presented, followed by a discussion and final conclusion.

SETTING UP THE THEORETICAL FRAMEWORK

As addressed in the introduction, this paper aims to increase knowledge about the role played by the artefacts found in the staff during large police operations, and how they are used in the collaborative work process to establish a COP. In this section the term *COP* and the staff will be discussed in relation to some of the work found in the CSCW domain.

The COP has similarities with intelligence (c.f Agrell, 2012) as Intelligence is often presented as being the product of a step-wise process meant for action, where information is gathered, analyzed and presented. The COP is also a product of a step-wise process during which a selection of available information is aggregated, analyzed and presented. The COP is intended to be a basis for action, which in a crisis consists of operational, tactical, and strategic decisions (Borglund et al., 2014). A COP has similarities with what Endsley (1995) defines as Situational Awareness. A COP is not primarily about perception, it is the product of a process in which information is collected, captured and analyzed for the purpose of presenting an analyzed picture of what is going on (Borglund et al., 2014). A COP can be seen as both an end product, which can be distributed and shared and also the ongoing process through which information is selected, analyzed with a purpose to better understand what is going on. The concept of a COP is applied in smaller single incidents, as well as in large complex emergency situations (Borglund et al., 2014). A COP as basis for decision supports the organization's capacity to meet upcoming threats and new unwanted situations, which is important for the organization's agility (c.f. Harrald, 2006).

The term COP centres on awareness of present events and, according to Dourish and Bly (1992), awareness involves "knowing who is 'around', what activities are occurring, who is talking to whom". For tactical and operational decisions the awareness is central for the police and the work being undertaken (Svensson, 2007). One example from the Swedish Police is the Gothenburg Window (figure 1) with four squares that give information about the place, direction, resource, and trend. Place is the physical location of the situation, Direction is a brief description of what is going on, Resource is a summary of the police units at site, and Trend indicates in which direction the police operation is going, e.g. status quo, escalating or calming down. The Gothenburg Window is inspired by staff guidelines, such as those found in Svensson (2007). The 'window' is intended to be put on a whiteboard in the staff meeting area where it supports easy visualization of the situation.

Place	**Direction**
Trend	**Resource**

Figure 1. The Gothenburg Window

Implicitly, this research also argues that the work of establishing a COP is based upon collaboration between actors involved in the management of large police operations. In the staff the goal is to establish something "common" which is difficult to achieve without collaboration. Amongst practitioners, the COP is necessary for strategic, tactical and operational decisions during a crisis.

The theoretical concept of artefactual multiplicity (Bjørn and Hertzum, 2011) has been used as an analytical lens to enable interpretation and understanding of the intertwined web of heterogeneous artefacts and the interaction between them in a staff context. In a staff, several artefacts are used during an extraordinary event and it is important to understand their relationship and multiple functions if modern information technology is being designed to support staff work. Bjørn & Hertzum introduced the concept of "artefactual multiplicity" in 2011, declaring that it "can be used as an analytical lens for identifying the multiplicity of collaborative artefacts.".. The concept "identifies not only the multiple functions of heterogeneous artefacts but also the *relations* between these multiple functionalities" (Bjørn and Hertzum, 2011, p. 118). They demonstrate that artefacts can hide complex multiple functions and relations between them, which must be understood if one aims to design better IT-support in an operations room, for example. Bjørn & Hertzum (2011, p. 99) argue for the notion of multiplicity due to the fact that "there is no one reality; instead multiple realities co-exist" and therefore it is important to investigate the various existing practices and realities of the artefact. "It is when multiple people engage in various practices involving the single artefact that it becomes a multiplicity" (2011, p. 99). In a police staff, many people with distinct roles (representing different communities) will interact with the artefacts. Yet another argument for applying the artefactual multiplicity is rooted in the underlying ideas in SET (Socially Embedded Technologies). The technological and the social are entangled and "people and artefacts become bounded in practice" (Bjørn, 2012, p. 98).

The contextual settings of interest in this paper are the temporal command settings that are set up during large police operations. In the CSCW literature, as presented in the introduction, there are examples of research where collaboration within permanent command settings have been studied (Filippi and Theureau, 1993; Heath and Luff, 1992; Luff and Heath, 2000; Pettersson et al., 2004). Even when the temporal command setting is using a permanent and physical room, it is still defined as a temporary organization. A temporary organization is characterized by its aim to deal with one specific purpose (Lundin and Söderholm, 1995), which for a police staff is about the management of the police operation.

This research studies what can be called common artefacts, i.e. the artefacts that are commonly found in a large police operation, and in the more temporary premises used for housing e.g. command posts, support of staff etc. Robinson (1993, p. 199) defined common artefacts as having certain characteristics that "... can support co-operative working in all its routine troubles without a need to anticipate particular contingencies, or the order in which they might arise". These common artefacts have the ability to provide a common information space (Schmidt and Bannon, 1992), as they make it possible for many users to work on the same information in collaboration. Examples of common artefacts are: flip charts, white boards, word processors, maps, video projectors. Common artefacts are not artefacts used by a small unit within the police as e.g. software for intelligence analysis used only by the P2 function (explained below).

According to Robinson (1993) a set of five dimensions form the characteristics of the common artefacts, which are:

1. They are predictable for the people using them.
2. There is peripheral awareness about what the artefact should be easily able to show, e.g. changes.
3. Implicit communications endow the artefact with the possibility to almost communicate by itself.
4. Double level language occurs when the implicit communication is combined and supported by explicit communication.
5. They can provide an easily interpretable overview of parts of the work space (Pekkola, 2003).

RESEARCH APPROACH

The paper rests upon qualitative research carried out as ethnographical field studies (Van Maanen, 1988), where five studies of varied length have served as data sources. Each study has contributed a separate data set. The use of artefacts used in police practice, are best studied in their context, i.e. in the organization (Braa and Vidgen, 1999) which is the reason why this study is based upon a qualitative research approach (Taylor and Bogdan 1998) and is taking place in-context, in the police organization. All five studies A, B, C, D, and E are the basis for this paper. Study A occurred during the EU Energy- and Environment-Ministers meeting held in Åre in 2009, between July 23 and 25. The meeting was a very large police operation managed by the smallest regional police authority in Sweden. The research was carried out between July 20th and July 25th. Study B covered a large regional disaster training exercise that took place in April 2010 in the County of Jämtland. The scenario was an airplane incident in which a Boeing 737 from Arlanda Airport crashed during landing at Åre-Östersund Airport. The exercise involved almost 1,000 participants, and aimed to test the region’s capacity to manage a large crisis. During this training exercise the data collection was confined within the police authority, but it also included two preparation days arranged by the police. Study C was a three-year longitudinal research project, Gaining Security Symbiosis (GSS) where the project’s main focus was to run three training exercises for the Norwegian and Swedish police, fire departments, municipalities, county administrative boards, and medical services. Study D was an educational exercise in a mid Sweden police authority. Study E consisted of active participation in two educational courses at the National Swedish Police Academy, each one week long. The two courses were “Introduction to staff work”, and “Chief of staff”. The researcher participated as a student in the first course and as one of the teachers of the second course. All participants in the course were informed of the researcher’s presence and that the researcher was there to collect data. The data was gathered during all of the minor exercises undertaken as part of the courses. When the researcher was a student the data was collected from a participant’s point of view, but during the second course it was collected as an observer rather than participant.

A summary of the studies together with data collection methods is presented in Table . The five studies have supported triangulation of the findings (as e.g. described in Myers, 2009).

Table 1. Summary of research studies

Study	Research context	Extent	Data collection
A	Police work during EU Energy and Environment Ministers meeting	6 days	Observation Interview
B	Police work during large regional disaster training exercise	1 day exercise 2 days preparation	Observation Interview
C	Collaborative cross national developing project focusing on arranging training exercise	Total 12 days	Observation Interview Network analysis Radio communication
D	Local police authority education and training	1 day	Observation Interview
E	Courses “Introduction to staff work” and “Chief of staff”	10 days	Observation, Interview

The data collection methods were primarily various forms of field studies with participatory observations. Short notes were taken in a notebook during the observations. At the end of each day the collected notes were summarized (see e.g. Taylor and Bogdan, 1998). In order to revisit areas of interest as well as gathering experiences from events not covered by the aforementioned observations, informal interviews were done (Kvale, 1997), recording these situations for clarification. Questions and answers were later transcribed in a notebook. During each study an on-going analysis was done with the goal of making sense of the activities observed and studied. The ethnographic approach has a strong research tradition within CSCW (Blomberg and Karasti, 2013; Schmidt and Bannon, 2013) and is very helpful in identifying design implications (Dourish, 2006; Dourish, 2007).

The main focus of the study and the data collection was to see how information was managed, i.e. created, captured, and used. This automatically included the study of the artefacts involved in the management of information.

The analysis of the data has been iterative, where the notes from the research have been manually revised and patterns and structure in the data were identified. The empirical data from studies 1-5 were re-analyzed by overlaying the theoretical concept of artefactual multiplicity upon the five data sets. The findings have also been discussed with two police superintendents who have been in charge of many large police operations, not only to verify the findings but also to identify any weakness in the data. The concept of artefactual multiplicity is not well tested theory and have not broadly been applied as an operational concept that can easily be put as a lens upon empirical data. Rather, the concept is a meant to help the researcher to look for the multiple functions and the relationships between the functions of the artefacts. A deeper understanding of how artefacts are used during extraordinary events implicitly provides design implications. Artefactual multiplicity as an analytical lens gives new flavours to the "tales from the field" (Van Maanen, 1988) that ethnographical studies normally provide.

HOW POLICE ORGANIZE THEMSELVES IN A STAFF

Below is a presentation of the way in which the police organized themselves as a staff in studies A-D. In Study E this structure was the one taught and trained. There were, of course, minor differences but for the purpose of this paper, this description covers the general strategy for organization used by the Swedish in order to give the reader a contextual awareness and knowledge of the research at hand. There is also a generic description of the workflow of the police staff, which is not normative, but is provided as an example of how the temporal work rhythm flows in a police staff.

The staffs were organized following the National standard for how large police operations should be arranged (Nylén, 2006), and had the following competences and units:

Chief of Staff

P1 – Human resource manager: Responsible for making sure there are enough police officers, that they get to rest when required etc.

P2 – Intelligence: Responsible for intelligence work during the extraordinary event.

P3 – Operational management: Responsible for coordinating the operational police work.

P4 – Logistics and equipment

P5 – Planning and co-operation: Supporting planning and establishing co-operation with other authorities

P6 – Operational analysis

P7 – Information: Responsible for information sharing with press and information gathering from the press.

P8 – Various tasks: Dependent upon the event, this position can have various aims.

P9 – Documentation: Responsible for capturing important decisions in the staff, and document them according to internal instructions.

The staff is normally located either in a specially designed room with lots of technology or in a room more like a conference room. Experiences from larger catastrophes and crisis in Sweden indicate that it is often common that the staff will work in a room that not is designed for the purpose of hosting a staff. It is not uncommon for the room where the staff meets and works to look like Figure 2 below: i.e. a room with white boards and video projectors Sometimes the staff works in operations rooms specially designed for that purpose, equipped with dispatch operation tables, fixed large whiteboards or mobile whiteboards, and video projectors.

On a daily basis 4-6 ordinary staff meetings were held (including meetings where staff teams take over from each other). During these meetings, the chief of Staff and the P1–P8 were gathered in the staff room and each of the support of staff members presented what new information had been received since the last meeting. The staff meeting was always documented in a word processor document that all were able access through the police intranet. Normally the staff meetings are where a more official COP is formed. Each P-function is represented and an aggregation of available and relevant information is made, to form the COP upon which all participants can agree. One can say that the COP developed during the staff meeting is a time stamped, shared, and documented understanding of what is going on.

Between the staff meetings each P-function reported all events judged as important to the Chief of Staff. It was then up to the Chief of Staff to decide if the entire support of staff should be gathered. This was communicated face to face, by telephone or by mail even if that was very rare. If the P-functions needed to document their work they used the ordinary police IT-systems available for this purpose. The P3-unit was the unit that had the main responsibility to manage and update the common operational picture, as it hadoperational responsibility for all police units on duty. The P-3 unit was divided into 3 subunits, *P-3T* responsible for the traffic, *P-3O* responsible for all other police units, and *P-3C* responsible for criminal investigations. The P-3 units had at least 2 dispatch operators that managed the radio traffic among the police units. The dispatch operator also recorded all on-going events in the command and control system. The P-3 unit plotted all upcoming events on whiteboards. For example in study A, they had the preliminary schedule of when they expected each minister to arrive at Östersund Airport. Every change was added in a different colour on the whiteboard.

Collaboration is embedded in the structure of the roles expected of staff. For example, Operational Management (P3) are reliant upon correct information from Intelligence (P2), and Logistics and Planning (P4) need to collaborate with the Human Resource Manager (P1).

Figure 2. The operation room, with all P-functions gathered around the table

Between the staff meetings each P-function either works in the room for the staff or they return to their own offices. If the situation is time-critical and the stress level is high, a higher tendency to stay in the staff room has been observed. When the staff room was a well-equipped operations room (as in studies A, B & D) the members of the staff tended to stay in the room throughout the entire operation. There are also some events that require the staff to work in the same room for security reasons. This requires functioning staff logistics supporting the staff with drinks, food and other necessary equipment.

USE OF ARTEFACTS

Use of the artefacts is presented in this section.

Computers and the documentation systems

Two computer-based systems were used for documentation and to share on-going activities. **1.** The command and control system (STORM is the name of the system), was used to record and log all operational activities. For example, if groups of police officers were sent to an address, this was logged in STORM, together with the reason. **2.** The more tactical and strategic decisions were documented using word processor software, and the documents were stored in common folders on the police intranet. All minutes were written and documented with a word processor, and stored in a common folder, or at a given location in the structure of common folders. In addition to the minutes, each P-function could write a "diary" of on-going activities, but not all P-functions did so. When the whole staff was gathered, there were discussions about what to document and if all agreed to document a situation, this was done. STORM could be running on a computer in the staff, and could also be projected on a wall with a video projector to enable sharing the content of the system. STORM is not available to everyone. It is normally used only by trained command and control central dispatchers. Therefore it is often projected upon a wall with a dispatcher controlling the system. The Chief of Staff uses STORM to record important operational decisions.

The word processor is used more as a hidden repository, since very few police officers read what others had written. Although each document was accessible from any computer connected to the police intranet, and each document had a file name and a time stamp, they were rarely used during the on-going work in the staff. However the documents were an important source enabling each P-function to update themselves at the start of a new shift. During longer crises the work in the staff can cover many days, and the documents served as a very important source for understanding what has happened and how the crisis has evolved, particularly for new personnel joining the staff. Going through the documents is time consuming and it is not easy to gain an overview. However, the documents were often found to be rich in information.

Whiteboards and flipcharts

Whiteboards are important in large police operations, which was very apparent in these studies. There were whiteboards used as operational plotting tools in every room used by the staff.

During Study A whiteboards were used to plot all planned events in chronological order. The plotting of planned events helped the staff to be prepared for the future and increase their knowledge of what was to come. If there was a change in the program, the information was updated and also marked as "updated".

Often whiteboards are used to plot the important decisions given either by the police operational commander or the strategic commander (which of course could also be found in documents in the common folders on the police intranet). However, when the decisions are shown on a whiteboard, all participants in the staff room are easily made aware of them.

The ease of documentation on a whiteboard makes them attractive for plotting important events that take place, i.e. as a timeline of the activities that affected the police operation. An example of such timelines can be seen in Figures two and three. If whiteboards are not available, adhesive "magic charts" are used instead (See figure 3). Whiteboards are often magnetic and therefore pictures or printed documents van be attached to the whiteboard with small magnets. These additional documents always relate to the text on the whiteboards.

When a whiteboard was filled with content as can be seen in Figure 3, they either prioritized documenting the content in a word processed document, or another whiteboard was brought in, upon which they continued to write, so the traceability was of high quality. Snap shots with a camera were sometimes used to document the content and the pictures stored with the documents in the shared folder.

The whiteboards were where the important information about on-going activities during the police operation was recorded in aggregated form. One whiteboard was also designated for the strategic commander to share a copy of the general decisions about the whole police operation, so all staff members could easily access and read the decisions.

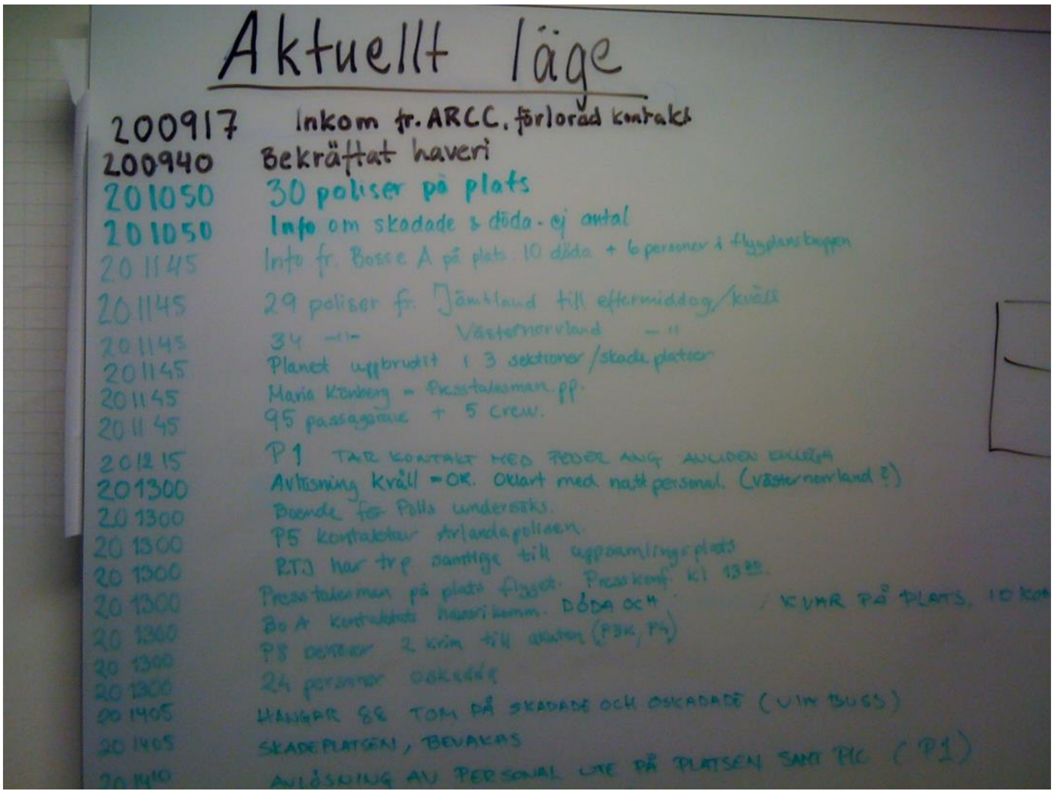

Figure 3. One whiteboard is used to plot all events in chronological order

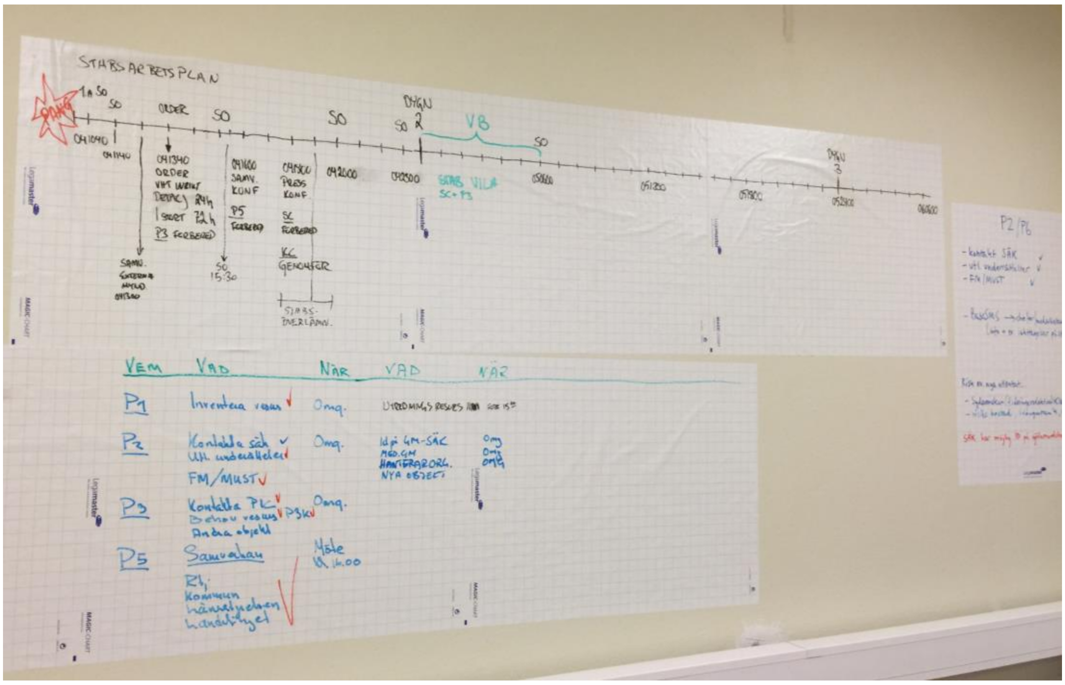

Figure 4. "Magic chart" used for plotting (picture from Study E)

During stressed and more chaotic situations it is common for the white boards to play an important role in documenting on-going activities and decisions taken. The person could write on the whiteboard at the same time as he/she was giving and receiving information over the mobile, and everyone in the room could immediately see what he/she wrote. In this research two of the studied staffs used three white boards as presented above. If something extra needed to be documented in the same way, the flip charts were used. The flip charts were used when there was a temporary need for urgent and easy documentation.

For example, during the training exercise (Study B) records were compiled of how many uninjured, injured, severely injured, dead, and missing people there were from the simulated plane crash site. This was plotted on flipchart papers instead of trying to find room on a whiteboard. Another example of flipchart use was when it was important to map out the location of all available police units.

Flipcharts were mostly used to document needs of a more ephemeral character. During the police operation in Åre (Study A), telephone numbers, call signs on the radio and flight numbers were the information most frequently reported on the flipcharts. When the information on the flipchart (or the charts on the wall) was no longer important for the management of the police operation, the chart was torn off.

Maps

Maps are artefacts traditionally used by the police. Every time a police unit intervenes in the surrounding society, a geographical location for the incident is documented and used for visualization in the police command and control system. During Study A the map was used to visualize and plot the locations of all the ministers, and of the police distance protection units in real time, in case a worst-case situation arose. They also used a map of the entire Jämtland region to to plan alternative escape routes for the motorcade, landing sites for the police helicopter and other spatial plotting needs. In Study A the same map was used by different P-functions for different purposes. During Study B, maps were used to plot rescue units' locations and the correct coordinates of the crashed airplane in order to gain an overview. Permanent plotting was done on an electronic map and projected on one wall. But when the map was used as basis for decisions, the staff sometimes used a printed map instead, and the persons involved put the map on a table and stood around the map, discussing, pointing, but not drawing on the map. Figure 2 shows both a map with plotting and a picture of the same area taken from a helicopter. In Study C, where the underlying aim of the project was cross-border collaboration, the maps always played an important role, aiding decision makers when asking for help from across the border. Sometimes maps were printed and put on the walls in the room to visualize the area of interest, for tactical reasons. When staff work is taught (in Studies D & E), maps are always exemplified as being an important tool for visualizing spatial challenges during a crisis.

AWARENESS AND COMMONNESS

An important component of the COP is promoting awareness of what is happening. The artefacts presented above and the ways in which they are used play an important role in creating this awareness. Whiteboards are artefacts are an easy means of sharing awareness. In all studies, the rooms in which staffs were placed were sufficiently small to allow each person in the room to read everything written on the whiteboards. The whiteboards also created awareness of on-going situations because they were quite easy for everyone entering the room to read. For example when the County Commissioner arrived, he could immediately update himself on what was going on by simply reading the whiteboard. The flipcharts similarly contribute toawareness. Text written on flipcharts is as easy to read as the whiteboards, but flipcharts also contribute to awareness in another way. When the flipchart is used only when there is an out of the ordinary need to document something visual, the flipchart will implicitly signal that something unusual has happened. When a new staff team started their shift they immediately realised that it had been a stressful session while they rested because there were so many flipcharts on the wall. All staff members know that the strategy is always to try to use only the whiteboards, and if they become filled with text, then that text is captured in either a document or a photo. Maps were used as static visualizations of an event, but it was also possible to make the map less static, and awareness that something was happening was created when things changed on the map. For example, small icons representing police units could be moved around on the map, so all could see them. The command and control system STORM, if projected on a wall, made everyone in the room aware of what was happening in the district (or what is recorded in the system). If it is not projected, each and every person is required to log into the system to keep up to date.

DISCUSSION – ARTEFACTUAL MULTIPLICITY

The discussion section presents identified multiple functions of the studied artefacts, the multiple roles that have been found, challenges encountered during establishment of a COP, and the presentation of the staff as an artefact.

Multiple functions

The main reason for using artefactual multiplicity as an analytical lens is to understand the multiple functions of the studied artefacts and the relationship between these functions.

For the whiteboard, the following functions were identified:

- **Documenting**: the whiteboard was used to document on-going activities, and was also a container for information waiting to be documented in a word processed document or recorded as a picture.
- **Scheduling**: plotting available resources, and the work schedule.
- **Planning**: plotting planned activities related to the police operation.
- **Signalling**: whiteboards covered in writing signalled that there is a need to transfer the documentation to other formats, as e.g. a word processor.
- **Increased importance**: when the police operation moved towards a more critical phase, the whiteboard became very important for the creation of the COP, and for documentation.

The word processed documents served as documentation of the police operation, and as a complement to the command and control system. It had two important functions:

- **Documentation of decisions** in the form of a 24-hour diary, but also recorded minutes from all meetings during the police operation. The documents were stored in command folders.
- **Indication of activities.** The sum of documents found in the common folders gave an indication of how much is going on at the other temporary command settings. Many documents indicate more activity and fewer documents indicate the opposite.

The maps were artefacts that had functions that meant to either support awareness or position police units or activities. But the maps also served as basis for operational and tactical decisions.

The flipcharts had the following functions:

- **Temporary documentation**. When there was a need to document activities, upcoming events, decisions etc. temporary flipcharts were used.
- **Emergency documentation**. Flip charts can also be seen as emergency documentation. If there was a need to document things more permanently, but documenting it in a word processor document was too time consuming, the flip chart was a good alternative. Once used, they could be torn down and saved as evidence.
- **Alert signal**. Due to the fact that the flipcharts were often used when something out of the ordinary takes place, the flipchart itself acts as a signal for all actors to be alert, and make sure to keep themselves informed about the situation.

Examples of the studied artefacts several functions are presented above. One of the reasons the artefacts are able to take on several functions is the multiple roles existing in the staff.

Multiple roles

Among the staffs studied there are ten pre-defined roles, all with a specific assignment and a specific area of responsibility. Thus there are ten roles also using the artefacts for ten different purposes. For example the P-3 function used the command and control system (STORM) to document important operational activities, but the P-1 function used the system to find information about who was working, and which police units were assigned to certain tasks. Each role can be argued to represent one internal police community, and that means that they also apply different functionalities to the studied artefacts. It is not only the use of the artefact that differs. The artefacts also "signal" different values to different P-functions. The data reveals that each P-function creates a commonly shared operational picture within the domain of their own P-function.

The way in which large police operations are managed and how the staff is organized is highly complex. It can therefore be concluded that a multiplicity perspective is preferable for describing how artefacts are used. This also implicitly supports the understanding of the establishment of the COP.

Common Operational Picture Challenges

The COP is the product of a process in which information is gathered, selected, analysed and presented. Based upon the data presented above the artefacts studied played an important role in that process. Artefacts could be used both to present a COP, but also to document the gathered information and highlight the selected information. In the process of creating a COP awareness cannot be neglected. The information gathering and the information selection is important, and depends upon awareness. In the staff it was obvious that each P-function needed to be aware of what other P-functions did, and what information they had gathered and selected. The awareness was therefore more about what was going on within the staff that about what was going on in the crisis situation for which the staff was initiated). However, there is a problem with ensuring awareness because of the analogue character of the studied artefacts. The whiteboards and the flipcharts, and to some extent the maps, all have limitations when it comes to the reach of the information and awareness to which they are able to contribute. It is important to understand that each of the studied staffs in this research create their own COP. This means that the "common" is only common for the actors of each staff, but in the definition of "common" other actors involved in the police operation are also included. This is, however, not new knowledge, but it confirms the results presented by Alvinius, A., Danielsson, E., Kylin, C., & Larsson (2007) where they claim that it is a challenge to manage one single COP based upon the many actors' different situation awareness. The artefacts studied are used both as the product of a COP, i.e. the result of the process in which information is gathered, selected, analysed and presented, but are also used as parts of each step in the COP-building process.

As indicated above the artefacts used in the staff are also used differently in relation to the temporal structure. When the situation is calm and everything is under control, much can be documented more permanently, and then also be accessed by others more easily. Things documented in a word processor in common folders have a longer reach beyond the staff than does a whiteboard, for example. The documentation is also more permanent. When a police operation turns into a more time-critical structure the ease and immediacy of using whiteboards and flipcharts increases the use of those artefacts.

One staff as one heterogeneous artefact

By applying the artefactual multiplicity, we understand that the web of artefacts used by, and in the staff, have multiple functions, and different actors use each artefact differently. The artefacts have links between them, as for example the links between the words on a whiteboard, which is, documented in a word processor file later on. It cannot be said that one type of artefact is more important than the others in the creation of the COP. It is possible to see the COP as a process; as an aggregation of all documented activities found in all artefacts. No single artefact is more important than any other. To understand the work that takes place in the staff one cannot study single artefacts in isolation. During large police operations, the work carried out in the staff and its use of artefacts is very complex. Each of the artefacts can be defined as being heterogeneous, part of an intertwined web of artefacts with links between them. To fully understand how these heterogeneous artefacts are used and how the collaborative work creates the COP the entire staff should be seen as one heterogeneous record of what has been going on, and the staff work should be understood from a holistic worldview. Treating an entire large artefact as a single record over complex activities is not new: the FBI did this when they treated the UNA bomber's entire cabin as a record of his criminal activity (McKemmish et al., 2005). However, this is a challenge when designing support for staff work.

Conclusion

This paper aimed to increase knowledge on what role is played by the artefacts found in the staff during large police operations (where the staff is the temporal organisational construct, established during extraordinary events to support their management) and how they are used in the collaborative work process to establish a COP. The paper focused on studying the interaction between the heterogeneous artefacts commonly found in a staff context, and applied the concept artefactual multiplicity (Bjørn and Hertzum, 2011). The purpose has been to understand how a COP is established in that setting. It is argued that the COP of one staff is documented in the intertwined mix of artefacts, and that awareness of what is happening cannot be visualized without this understanding. Without the use of artefacts it would be very difficult to establish a COP, especially if the artefacts did not offer functionalities allowing visualizion of on-going activities.

This research implicitly aimed to contribute an understanding of how collaborative technologies could be designed to support the establishment of COPs. The research also contributes a deeper understanding of factors in designing for the facilities in which staffs work so that they are spaces with potential. In summary, two contributions have been made. First, knowledge on how the artefacts are used in the establishment of the COP during large police operations has been provided. Second is the proposal to study the whole staff and the artefacts it uses as one heterogeneous unit, which would thus provide a record of the staff's activities. Studies of single artefacts in isolation reduce the possibility of seeing the full multiplicity of all the artefacts used in the staff, and the complexity of the intertwined web of their artefactual functions.

This research has focused upon situations where the COP is established for one single staff. During large extraordinary events, it is not unusual for the police to establish separate staffs at national, regional, and local levels. How a COP is established between several staffs has not been studied, nor how the artefacts are used to collaboratively establish a COP between various staffs. These are potential topics for future research.

ACKNOWLEDGEMENT

This work was supported by the Interreg Sweden-Norway program [No: 20200037].

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Assessing command and control teams' performance and agility

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ABSTRACT

Crisis response organizations and military units must be agile and able to adapt to dynamic situations. The ability to adapt includes command and control agility, organizational adaptability and individual adaptability. An exploratory study of these adaptability traits were undertaken during a naval exercise. The exercise scenario was designed to progressively become more challenging, suggesting decreased performance and adaptability over time. The study objectives were to develop a data collection approach for adaptability traits and to investigate association between these traits and performance. Data collected from four command teams were evaluated in terms of response rate and item variation. Principal component analysis was used to explore latent structures and relationships. The results indicate acceptable survey response rates and trends showing a decrease in organizational adaptability and C2 agility over time while individual adaptability increased. The analysis also identified five partially independent components in the latent structure.

Keywords

Command and control, Agility, Adaptability, Performance assessment

INTRODUCTION

In routine emergency management such as traffic accidents responders are usually well acquainted with most responding agencies' standard operating procedures. Coordination is almost implicit and need for collaboration low (Berlin & Carlström, 2008). However, coordination is much more complicated in unexpected crises or major disasters such as Hurricane Katrina (Koliba, Mills, & Zia, 2011). Such crisis response operations are characterized by surprise, uncertainty and a need for collaboration and improvisation among entities in order to coordinate actions in time and space (Curnin & Owen, 2013; Curnin, Owen, Paton, Trist, & Parsons, 2015). The theory of command and control (C2) agility predicts that organizations who can adapt their way of exercising C2 in dynamic situations stand a better chance to handle the variation associated with such crises and disasters (NATO STO SAS-085, 2014).

This paper presents findings from an exploratory study of adaptability and agility during a Swedish naval exercise in 2016. The study is part of a research program with the aim of developing and adapting approaches to assess future naval operational Command and Control (C2) capability, including identification of relevant measurable factors reflecting maritime adaptability as well as finding valid and reliable methods for collecting data with respect to personal integrity, workload, security policy and other practical restrictions. In a series of naval exercises, different methodological approaches have been successively explored and developed (Wikberg, Johansson, and Andersson, 2016).

The objectives of this study are 1) to identify opportunities and challenges in data collection from command team members for adaptability assessment in a maritime operations setting, and 2) to gain understanding of how to assess command teams' performance by investigating how different adaptability traits are associated with performance. These research objectives have been studies specifically in the context of the Swedish navy, for which a particular challenge is that of obtaining repeated measures from command teams during distributed operations since their work environment is too confined to allow the use of dedicated observers for on-site data collection while at the same time the communication environment only allows for limited non-mission-critical communication.

Command and control in the Swedish Navy

Swedish naval C2 are based on the principle of *mission command* (Försvarsmakten, 2016). Mission command is the principle in which details about how to solve a task are decided by the commander responsible for the execution (U.S. Army, 2012). Consequently, commanders in the Swedish navy give orders in terms of goals and assign resources, allowing subordinate commanders to autonomously decide how to fulfil the superior commander's intent.

During operations the Swedish Navy implements mission tailored *task organizations* (TaO) which are separate from the regular peace time *type organization* (TyO) with flotillas and regiments. The TaO consists of up to four organizational levels (Försvarsmakten, 2010):

- *Task Element* (TE). A TE consists of a vessel and/or unit.
- *Task Unit* (TU). A TU is a set of TEs and designed to solve designated tasks within the task groups overall mission.
- *Task Group* (TG). A TG is a set of TEs and TUs designated to solve a maritime operational task.
- *Task Force* (TF). A TF is the command normally executed at the highest navy command level, the *Maritime Command Component* (MCC). The TF can for example be a combination of TGs from the fleet, amphibious units, helicopter units and logistics.

Adaptability and agility

Adaptability can be viewed as the ability of a system to change - which is also sometimes referred to as agility (Hoffman and Hancock, 2017; Alberts and Hayes, 2003). This broad definition covers aspects such as changing processes, culture, equipment, tactics, leadership etc. The scope of the research program is assessment of C2 adaptability and the focus of this explorative study is performance and agility among Swedish navy command teams. Successful C2 agility connects and orchestrates organizational units and capabilities during adverse events, allowing for organizational adaptability. As humans are a main source for adaptability, we can also approach C2 agility and organizational adaptability from the individual point of view. By assessing the traits of C2 agility, organizational adaptability and individual adaptability, a holistic evaluation can be made.

C2 agility – approach to coordinate actions

C2 in military organizations has been studied from an agility perspective, defining agility as *"the capability to successfully effect, cope with and/or exploit changes in circumstances"* (NATO STO SAS-085, 2014). An assumption is that no single C2 approach is perfect for all kinds of situations. Instead, each type of mission corresponds to an optimal C2 approach, organizations, or collectives of organizations, who encounter a broad range of mission types must maintain a level of flexibility to adapt their C2 approach, i.e. maintain an adequate level of C2 Agility (Johansson, Wikberg, and Andersson, 2016; NATO STO SAS-085, 2014; Vassiliou Alberts, and Agre, 2014).

A conceptual tool for describing C2 agility is the *C2 approach space* (NATO STO SAS-065, 2010), a three axis model presenting the C2 approach in terms of *distribution of information*, *allocation of decision rights* and *patterns of interaction*. The appropriateness of a C2 approach can be evaluated in the light of the situation and problem in which it is applied – *the C2 problem space* (Alberts and Hayes, 2006). Sometimes each involved entity might act separately, with required coordination handled at the top command level (referred to as *de-conflicted C2*). More complex and unpredictable situations may require entities to collaborate on multiple levels concurrently (referred to as *collaborative* or *edge C2*). The ability to recognize the need to change C2 approach and to perform the change is what constitutes the C2 agility (NATO SAS-08, 2014). Consequently, agile C2 systems are expected to be projected onto different locations in the C2 approach space as the situation changes.

Organizational adaptability – detect and manage unexpected events

Improvisation theory state that organizational improvisation is "an adaptive response to unexpected or unanticipated situations that are outside the boundaries of what an organization has prepared for" (Trotter et al., 2013, p. 476). An organizations ability to adapt and respond to an unexpected crisis depends on number of factors such as *capabilities*, unique skills that an organization performs, *capacity*, how many resources or trained personnel an agency has and *proficiency*, how well an organization performs each task (Pfeifer, 2005). An organizational unit, cut off from communication with higher command or other functions for coordination, can still adapt successfully to a situation if it is capable, proficient and has enough capacities. Consequently, an organizations ability to change concerns more than C2 agility.

Two organizational abilities are critical in order for an organization to change successfully to the demands of a situation. *Ability to detect abnormal events*, concerns the ability to predict, monitor, and understand changes in the environment. This is a prerequisite to response as the system must have the ability to predict or detect deviations and threats to make conscious decisions on countermeasures. *Ability to deal with abnormal events*, concerns the ability to cope with deviations when they occur and the ability to withstand damage and use resources in a flexible manner (Johansson et al., 2016). Presumably, these abilities varies over time and between different situations.

Individual adaptability – requirements on the role

In contrast to the C2 and organizational view on adaptability, a different perspective is based on the assumption that different types of situations require different forms of adaptive behavior by the individuals. Pulakos, Arad, Donovan, & Plamondon (2000) defined adaptability as involving *creative problem solving*, *coping with uncertainty*, *learning new tasks and skills*, *adapting to teamwork and collaboration*, *changing and developing new procedures*, and *adapting across cultures*. The definition is based on analyses of workplace challenges and suggestive for a method for job analysis. Consequently, the role for the individual in an organization may require different types of individual adaptability skills. Hart and Oprins (2015) have taken this notion one step further and outlined an approach aiming at an instrument to measure the adaptive behaviors in relation to organizational requirements, and individual preferences. According to the theory, the organization's performance can thus be increased by successfully matching individuals' adaptability profiles with role adaptability profiles. One could expect that these requirement varies over time during a crisis response operation.

METHOD

The study was undertaken as an exploratory case study during the last 5 days of the 10 day SWENEX 16 exercise. The study was planned in conjunction with the Navy's exercise planning, in close collaboration with the exercise evaluation cell (EXEVAL).

Scenario

SWENEX 16 was a live exercise that took place between November 14 and 23, 2016, in the Baltic Sea north-west of Gotland (Figure 1).

Figure 1. Area of exercise for SWENEX 2016.

Around 2,000 individuals, 20 large vessels and several small assault and patrol crafts were engaged in the exercise. In addition, helicopters and jetfighters from the helicopter flotilla and the Airforce participated. The naval WaO consisted of one TF organized into five TGs: Surface TG, Submarine TG, Amphibious TG, Helicopter TG and Logistics TG. The TF was commanded by the Maritime Command Component (MCC) at the Armed Forces Headquarters. The Navy's exercise objectives included training of naval command and control, and coordination and cooperation with other maritime actors.

The exercise scenario background was a tense security situation. For the major part of the exercise the Navy prepared and executed a maritime security operation in a context were a foreign power acted to limit Sweden's military engagement in the area. During the exercise, the situation deteriorated and hostility escalated. Due to the increased tension and some incidents, the Task Force gave orders on Monday November 21 to the TG:s to change the operation into coastal defense. On Tuesday 22 the situation turned into open conflict and vessels were sunk on both sides. The opponents primary goal was however not to invade Sweden. Instead main actions were directed towards a third country. Political negotiations made it possible to reach a cease fire agreement on Wednesday 23.

Design

The study was designed as an exploratory case study.

The first objective, *to identify opportunities and challenges in data collection from command team members for adaptability assessment in a maritime operations setting*, was realized by testing a survey for periodic response by selected staff members in different TGs. The survey included 19 items related to the adaptability traits and two performance items. The feasibility of the survey was evaluated through response rate analysis and how items varied over days. The second objective, *to gain understanding of how to assess command teams' performance by investigating how different adaptability traits are associated with performance*, was realized through a principal component analysis (PCA) of survey data using a rotated solution in order to analyze whether there were any latent structures and relationships between the adaptability traits and performance.

Participants

Four of the five TG staffs participated in the data collection: surface (SuTG), logistics (LogTG), amphibious (AmphTG) and helicopter (HeliTG). These staffs were represented by appointed representatives from five different staff functions. Table 1 below shows the roles in each staff planned to provide data. Each row in the table denotes one TG staff, with the corresponding role prefix letter in parenthesis. The columns represent staff commander (Cmdr.), chief of staff (COS), and staff functions with the staff number in parenthesis[1]: intelligence/security (2), operations (3), logistics (4), plans (5) and communications/signals/IT (6). The roles in the table marked with an x are those that were tasked to contribute to the data collection. SuTG N3 and N5 are marked with / to denote that the staff functions for planning and operations in SuTG were merged during the exercise, and consequently these have been treated as one role in the analysis. Further, AmphTG S3 has been marked L1-3 to highlight that this role was represented in three different command posts L1, L2 and L3 and consequently corresponds to three roles. Consequently, 21 roles were expected to provide data. As the exercise was a 24/7 live exercise lasting several days, each role could be manned by different individuals in some of the TGs. However, no comparison was done on the individual level. Consequently, only role and TG were registered as identifiers in the survey.

Table 1. TG staff roles. Each role marked x was included in the data collection. Roles marked with / were merged and manned by the same individuals and consequently included and represented as one data point. AmphTG S3 existed as three command posts, each representing one intended point for data collection.

	Role						
TG staff	Cmdr.	COS	Intel. (2)	Ops. (3)	Log. (4)	Plan. (5)	Comms. (6)
SuTG (N)		x	x	/		/	x
LogTG (N)		x	x	x	x	x	x
AmphTG (S)	x	x	x	L1-3	x		x
HeliTG (A)	x				x	x	

Data collection

The survey together with instructions was distributed as part of the Navy's exercise plan. The exercise management organization at each TG then secured distribution to participants. Responses were collected from the roles identified in Table 1 at the end of each watch during the period from the evening of November 18 until the morning of November 23, 2016. In each response to the survey, the participants were asked to assess the situation during the completed watch. A digital file with the response was be submitted to the EXEVAL upon

[1] according to the continental staff system, also known as the great general staff system, see: https://en.wikipedia.org/wiki/Staff_(military)

completion and subsequently handed over to the analyst.

The questions were clustered into five themes, two for organizational adaptability (OA), one for C2 approach agility (C2A), one for individual adaptability (IA), and one for perceived performance. All questions were to be answered in a 7-degree Likert scale anchored at "1: not at all" and "7: to a very high degree" unless otherwise noted. The questions are listed together with each theme below.

Organizational ability to detect deviating events

The first set of survey questions refers to organizational adaptability and how much potential there is for the system to detect and understand a deviating event and to disseminate this information within their own system. These questions were based on a proposed tool for measuring C2 agility and resilience in socio-technical systems (Johansson et al., 2016).

Q1 To what extent have you had access to information about current threats?

Q2 To what extent have you had access to information about own (TF, TG) situation?

Q3 To what extent have you been able to disseminate important information on events related to current threats?

Organizational ability to deal with deviating events

Survey questions Q4-Q8 refer to the ability to cope with deviating events, including proactive measures proactive preparations and flexibility to allow system reconfiguration to better handle unanticipated deviating events. As for the previous set, these questions were based on Johansson et al.'s tool (2016).

Q4 To what extent have you been able to handle/resolve important events concerning current threats?

Q5 To what extent have you had different alternatives for handling important events?

Q6 To what extent have you been able to deviate from normal procedures/SOPs?

Q7 To what extent do you feel that there have been preparations to meet unexpected events?

Q8 To what extent do you feel that there is redundancy in your function?

C2 approach agility

The third cluster of survey questions refers to the ability of the system to maintain command functions within the frames of the designated mission space (NATO STO SAS-085, 2014). The items in this theme correspond to changes along the dimensions on which the C2 approach space is described in C2 agility theory: 1) ability to allocate decision rights, 2) ability to distribute information, and 3) ability to interact.

Q9 To what extent do you think the decision mandate has been allocated appropriately within your TG?

Q10 To what extent do you think that relevant information is distributed within your TG?

Q11 To what extent do you feel that it has been possible to coordinate within your TG?

Q12 To what extent do you feel that it has been possible to coordinate with units external to your TG?

Individual adaptability

The survey questions on individual adaptability refer to the characteristics of the working conditions defining which adaptable behaviors are required by individuals for their assigned work roles, based on the taxonomy of individual adaptability behaviors (Hart and Oprins, 2015). No item regarding adaption across cultures were included as the study only included Swedish naval officers.

Q13 To what extent has your work situation been characterized by coordination/collaboration with others?

Q14 To what extent has your work situation demanded crisis management?

Q15 To what extent has your work situation demanded creative problem solving?

Q16 To what extent has your work situation been characterized by uncertain and unpredictable situations?

Q17 To what extent has your work situation been characterized by the need to learn new equipment, systems or procedures?

Q18 To what extent has your work situation been characterized by high physical workload?

Q19 To what extent has your work situation been characterized by stress?

Perceived performance

To complement the questions on C2 approach agility and individual and organizational adaptability, the rating section of survey concluded with two questions on perceived performance, one regarding the respondent's own staff function in the context of the TG which the staff belongs to, and the other regarding the TG as a whole. These questions were answered on a 7-degree Likert scale anchored at "1: not at all" and "7: very well".

Q20 How well do you think your function has been able to perform?

Q21 How well do you think that your TG has been able to perform?

Analysis methods

All survey questions were worded in a way that high values indicated high levels of adaptability or performance, except those on individual adaptability which rated working conditions that are assumed to reduce adaptability and performance. The scale for these items was therefore reversed in order to homogenize the dataset so that indicated high values correspond to high adaptability/performance.

Response rate analysis

The survey data was scheduled for transmission to EXEVAL after the completion of a watch, once the duties of that role had been handed over to the next watch. This means that each role were planned to submit two data samples per day, except for the first and last day of the duration of the data collection period, given the assumption that there were two watches per role and day. In total each role thus constituted 10 data collection points, which with 21 roles means that the maximum number of responses would correspond to 210 samples. The response rate would then be calculated as the ratio between the number of actual responses and the maximum number of responses.

Exploratory response profile analysis

For the variance analysis of adaptability survey items, the mean value of collected responses per survey item per day was calculated. Each survey item was then categorized according to how the mean responses changed between days. Four different profiles were used for the categorization: flat, decreasing, increasing and varying (Figure 2). The classification of items were based on how much they deviated each day from their own total mean (M). The cluster of items with the relatively lowest daily deviation from their own total mean (M) were classified as *flat*, with the threshold for this variation selected after initial variance analysis of the dataset. The rest of the items were classified as *decreasing* if $M_{n+1} \leq M_n$, *increasing* if $M_{n+1} \geq M_n$, and *varying* in all other cases. The varying items were thereafter further classified depending on the number of local optima between the endpoints and their character. Variations with one local optimum were classified as *vary/hat* or *vary/dip* depending on whether the optimum was a maximum or a minimum. Items with two local optima were classified as *vary/increasing* or *vary/decreasing* depending on whether the initial and final derivatives were positive or negative. Items with more than two optima were manually inspected for approximate fit with other profiles, alternatively classified as *vary/wave* or *random*. Finally, all calculated profiles were manually inspected and reclassified where the coarse classifications were deemed too rough or slightly off-target.

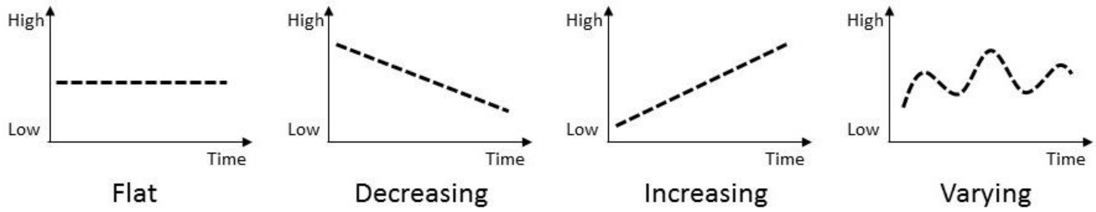

Figure 2. Each survey item was categorized into one of four moving mean profiles, based on the collected survey responses.

Principal component analysis

The 21 Likert scale questions from the survey were run through a PCA in order to analyze whether the manifest variables could be reduced to a set of fewer latent components. Initially, the Kaiser–Meyer–Olkin measure of sampling adequacy (KMO) (Kaiser, 1960) was calculated, with successive removal of variables with low measures of sampling adequacy (less than .50) until the KMO was considered good, i.e. above .70 (Sofroniou & Hutcheson, 1999). Further confirmation of the factorability was gained through Bartlett's test of sphericity (Bartlett, 1937).

The factor extraction for the PCA used oblique rotation (direct oblimin method) and the Kaiser criterion to determine a baseline for the number of generated components, i.e. retaining components with eigenvalues greater than 1 (Kaiser, 1960). The number of components was thereafter validated against a scree plot to confirm whether the number should be increased or decreased.

Potential links between the latent components were analyzed by using the component correlation matrix. Once identified, the final set of components were named based on the interpretation of the corresponding manifest variables. The latent components were then analyzed by content in order to estimate whether they should be divided into subcomponents.

RESULTS

The results in this section are presented, grouped per analysis method: response rate analysis, response profile analysis and factor analysis.

Response rate analysis

One of the four TGs were unable to respond to the periodic surveys due to force majeure. Data were obtained from each of the remaining three TGs, as detailed in Table 2 below. The actual activity during nights was lower than anticipated which resulted in responses once per day instead of the initially expected two. In addition, no responses were obtained for the last day, the 23th, due to a somewhat earlier completion of the scenario than expected. Consequently, data was obtained once a day for five days, with 13 responding roles instead of 21. A complete dataset thus corresponds to 65 responses instead of the originally planned 210. In total 46 responses were obtained, corresponding to a total response rate of 22% of the initially sought set of responses and 71% of the actually obtainable dataset given the operational circumstances. A large portion of the missing data stems from LogTG who were unable to respond to the survey on the 22th. All obtained responses came with complete answers on all questions except for one questionnaire which had omitted Q21. This single missing value was imputed with the mean value for the item since removing the entire response would undisputedly have negatively affected the dataset more.

Table 2. Number of responses per day and TG, followed by response rate based on the maximum obtainable sample rate adjusted after operational circumstances.

	18	**19**	**20**	**21**	**22**
SuTG (4)	4	4	4	4	4
HeliTG (3)	3	1	2	3	2
LogTG (6)	4	4	4	3	0
n (N=21)	*11*	*9*	*10*	*10*	*6*
Response rate	*85%*	*69%*	*77%*	*77%*	*46%*

Exploratory response profile analysis

A daily mean was established for each survey item Q1-Q21. The response profile analysis was conducted on data from all five days, despite the drop in response rate for day 5. Because of this difference in N, a complementary analysis was conducted on the SuTG alone, since this TG was the only to achieve a perfect response rate for all sample occasions. This complementary analysis was used to clarify whether any notable effects on the last day pertain from actual differences in work situation or if they are more likely to depend on sampling. The left portion of Table 3 displays the average of daily means (M), average standard deviation (SD), maximum negative deviation of daily means from average mean (Dev_-), maximum positive deviation of daily means from average mean (Dev_+), and finally the profile classification for the total dataset. The right portion of the table displays the same statistics for the dataset corresponding to SuTG only. The far right column displays an overall profile classification based on the two preceding analyses. The Dev_- and Dev_+ values are expressed in portion of the total average SD (1.373 and 1.393 respectively).

Table 3. Overview of categories of response profile for the different survey items. The left portion corresponds to the dataset including all TGs, while the right portion concerns only SuTG for which a perfect response rate was obtained. Each set is summarized with a detailed profile classification of the answers. The right-most column corresponds to a more generic profile classification based (flat, decreasing, increasing and indeterminate).

		All TGs					SuTG only					Profile class
		M	SD	Dev_-	Dev_+	Profile	M	SD	Dev_-	Dev_+	Profile	
Org adaptability	Q1	4.98	1.329	-83.5%	34.6%	Vary/Decr	4.75	1.297	-89.7%	89.7%	Decr	Decr
	Q2	5.01	1.241	-110.1%	38.9%	Vary/Decr	4.60	1.369	-114.8%	64.6%	Decr	Decr
	Q3	4.36	1.877	-26.2%	17.5%	Flat	4.30	1.598	-75.4%	50.2%	Vary/Hat	-
	Q4	4.36	1.518	-38.2%	24.9%	Vary/Decr	4.90	1.435	-82.5%	43.1%	Vary/Decr	Decr
	Q5	4.50	1.258	-73.1%	28.1%	Vary/Hat	4.45	1.409	-68.2%	57.4%	Vary/Hat	Decr
	Q6	4.70	1.360	-51.1%	21.7%	Vary/Hat	4.85	.718	-78.9%	28.7%	Vary/Hat	Decr
	Q7	4.43	1.084	-23.4%	41.4%	Vary/Decr	4.65	1.141	-46.7%	43.1%	Vary/Decr	Decr
	Q8	4.39	1.933	-40.6%	22.5%	Vary/Hat	4.30	2.140	-39.5%	32.3%	Decr	Decr
C2 agility	Q9	4.94	1.069	-11.7%	17.7%	Flat	5.05	1.168	-21.5%	14.4%	Flat	Flat
	Q10	4.52	1.055	-37.6%	21.9%	Vary/Decr	3.90	1.041	-28.7%	25.1%	Flat	-
	Q11	5.25	1.105	-79.2%	30.1%	Vary/Decr*	4.75	1.038	-89.7%	35.9%	Vary/Decr	Decr
	Q12	4.61	1.553	-93.2%	36.3%	Vary/Hat	4.45	1.777	-68.2%	75.4%	Decr	Decr
Ind adaptability	Q13	2.65	1.323	-32.8%	86.2%	Vary/Incr	3.30	1.600	-39.5%	68.2%	Incr	Incr
	Q14	5.67	1.551	-57.1%	43.7%	Vary/Dip	5.60	1.529	-61.0%	28.7%	Vary/Dip	Incr
	Q15	2.91	1.463	-33.6%	55.4%	Vary/Dip	3.50	1.640	-71.8%	71.8%	Vary/Dip	Incr
	Q16	3.09	1.448	-21.2%	29.8%	Flat	3.35	1.898	-43.1%	46.7%	Vary/Decr	-
	Q17	4.22	1.755	-23.1%	44.9%	Vary/Incr	5.45	1.380	-32.3%	39.5%	Vary/Incr	Incr
	Q18	5.77	1.167	-19.9%	23.1%	Flat	6.20	.790	-68.2%	39.5%	Vary/Decr	-
	Q19	4.33	1.702	-56.0%	73.4%	Vary/Dip	5.00	2.031	-71.8%	35.9%	Vary/Dip	Incr
Perf	Q20	5.46	.944	-33.8%	14.7%	Vary/Hat	5.35	.895	-43.1%	28.7%	Decr	Decr
	Q21	5.36	1.099	-13.9%	10.4%	Flat	5.20	1.365	-14.4%	21.5%	Flat	Flat
	Avg	5.36	1.373				4.66	1.393				

Four adaptability trait items and one performance stood out as a cluster with a relatively lower deviation from their own total mean. None of these had max and min deviation in relation to the total standard deviation above 30%, hence this was selected as the threshold for flat response profile. Items above 30% were thereafter classified according to the predefined profile schema. All items in the full dataset had one or two local optima, except Q11 which had three local optima, although its first local maximum (the day 2 mean value) is only marginally higher than the day 1 mean value, and is consequently not treated as an optimum. The item, marked with an asterisk in Table 3, has thus been reclassified as if it had two optima, e.g. vary/decreasing in the AllTG dataset. The same analysis was conducted on the SuTG dataset, which identified one survey item as *increasing*, i.e. Q13 relating to collaboration. The *decreasing* profile corresponds to five items in the SuTG dataset, all relating to the ability to exercise C2 and the ability to handle abnormal events. This confirmatory profile classification on the SuTG dataset was consistent with the full dataset on most items, confirming trends on a more generic scale as either Increasing (both ratings are *Incr*, *Vary/Incr* or *Vary/Dip*), Decreasing (both ratings are *Decr*, *Vary/Decr* or *Vary/Hat*), Flat or Indeterminate (-). Figure 3-5 illustrates the varying profiles for the AllTG profiles.

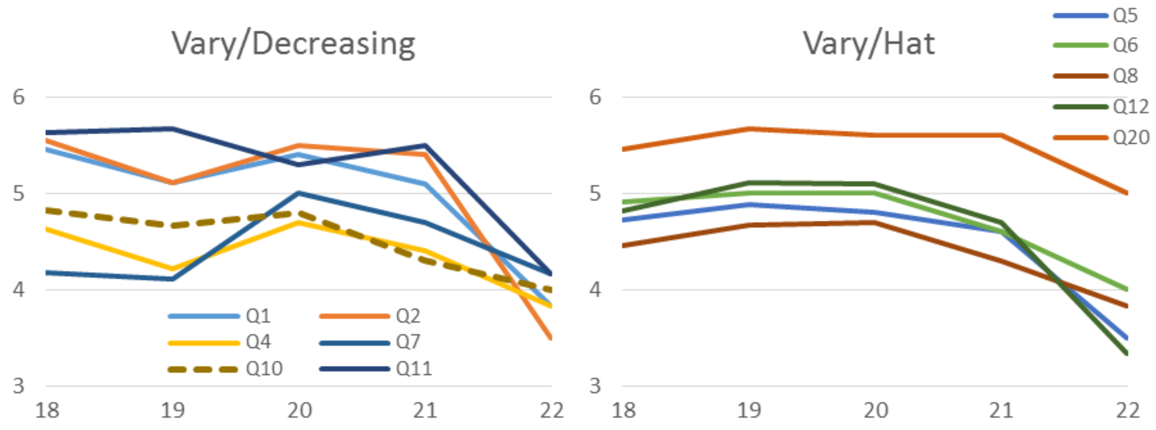

Figure 3. Profile graphs for survey items from the AllTG dataset that decrease towards the end of the exercise. Solid lines have been classified as *decreasing*, while dashed lines are classified as *indeterminate* due to mismatch with the SuTG dataset.

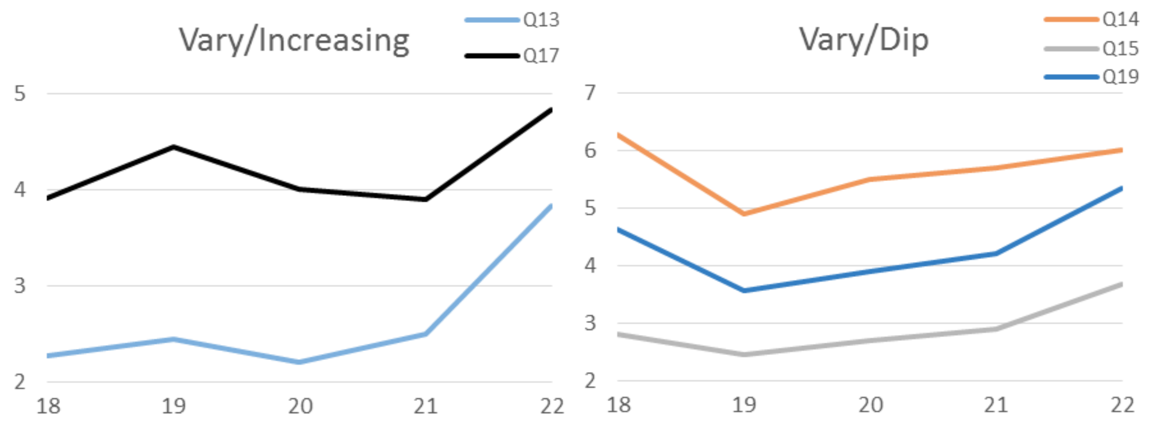

Figure 4. Profile graphs for survey items from the AllTG dataset that increase towards the end of the exercise. Solid lines have been classified as *increasing*.

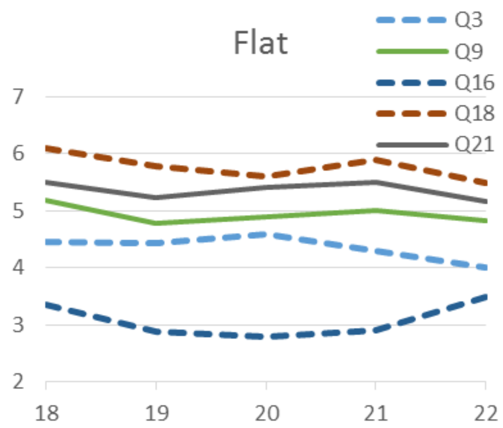

Figure 5. Flat profile graphs for survey items from the AllTG dataset that are relatively stable throughout the exercise. Solid lines have been classified as *flat*, while dashed lines are classified as *indeterminate* due to mismatch with the SuTG dataset.

As seen in Table 3 and Figures 3-5, ten survey items relating to C2 agility and organizational adaptability were classified as decreasing, two were indeterminate and two flat. One additional decreasing survey item, Q20, corresponds to individual performance, and likewise Q21 pertaining to TG performance was categorized as flat. Five out of the seven individual adaptability items instead display a positive trend, increasing towards the end of the exercise. The other two survey items in this category were indeterminate. Finally, many items has a distinct change between November 21 and November 22 corresponding to when the operation changed to coastal defense.

Figure 6 illustrates distribution of response profiles for each survey item in terms of deviation from the mean SD plotted against average daily SD. Through this chart it can be seen that Q9 and Q21 have low variance and high homogeneity among the responses, implying that there is indeed little change between the days in how the respondents answer these questions. Question 3 on the other hand shows a high daily average SD, implying a lack of agreement among the respondents. Since the flat profile is based on mean calculations, this could be a result of opposing changes that neglect each other in the mean analysis. The same type of analysis show that the indeterminate response profiles (Q10, Q16 and Q18) are fairly homogeneous, making them interesting for further analysis.

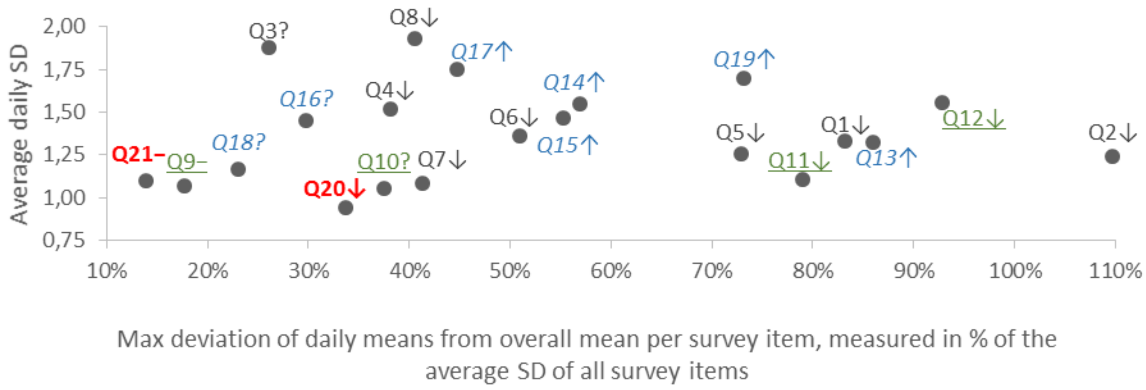

Figure 6. The maximum deviation of the daily mean from the total mean, for each survey item, plotted against the average of their daily mean standard deviations. Gray items relate to C2 agility, underlined green to organizational adaptability, italic blue to individual adaptability and bold red to performance. Each point has been labelled with their survey item number, suffixed by arrows representing whether their response profiles have been categorized as increasing (↑), decreasing (↓), flat (-) or indeterminate (?).

Q9 and Q21 have been confirmed to be stable. Figure 7 displays a plot of each individual's responses to Q9 for each day, juxtaposed with Q21. There is undoubtedly some variation among the answers, yet the responses are considered stable enough to retain the original estimation of their response profiles as flat.

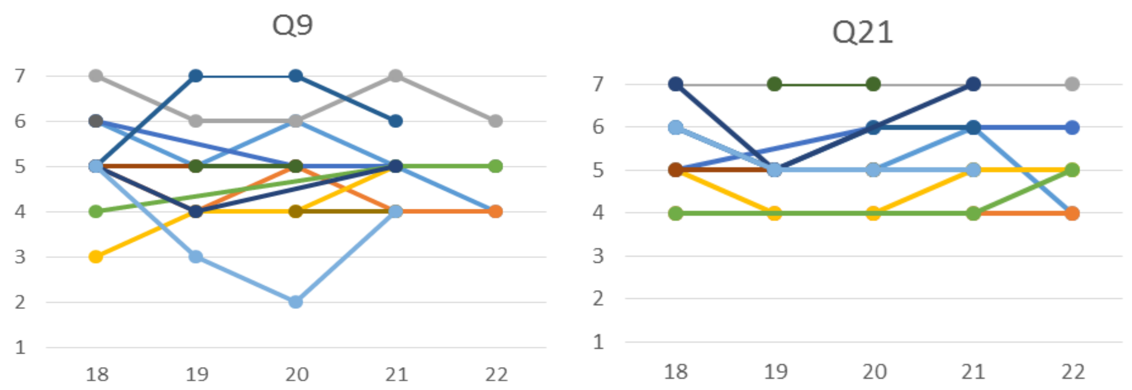

Figure 7. The daily responses for each respondent to Q9, juxtaposed with Q21.

In a similar manner as the flat profiles were analyzed more carefully, the items previously rated as indeterminate are displayed in Figure 8. Arguably Q18 could be seen as fairly stable up until the final day, during which those that did respond have lowered their assessments, thus the profile seems to be decreasing. Q18 is therefore changed to decreasing. Q3, Q10 and Q16 are all fairly stable among some of the respondents, although not necessarily in agreement. Since a few respondents have are spread their answers across the whole spectrum with opposite trends, while others have remained consistent in their ratings, the final verdict remains indeterminate for Q3, Q10 and Q16.

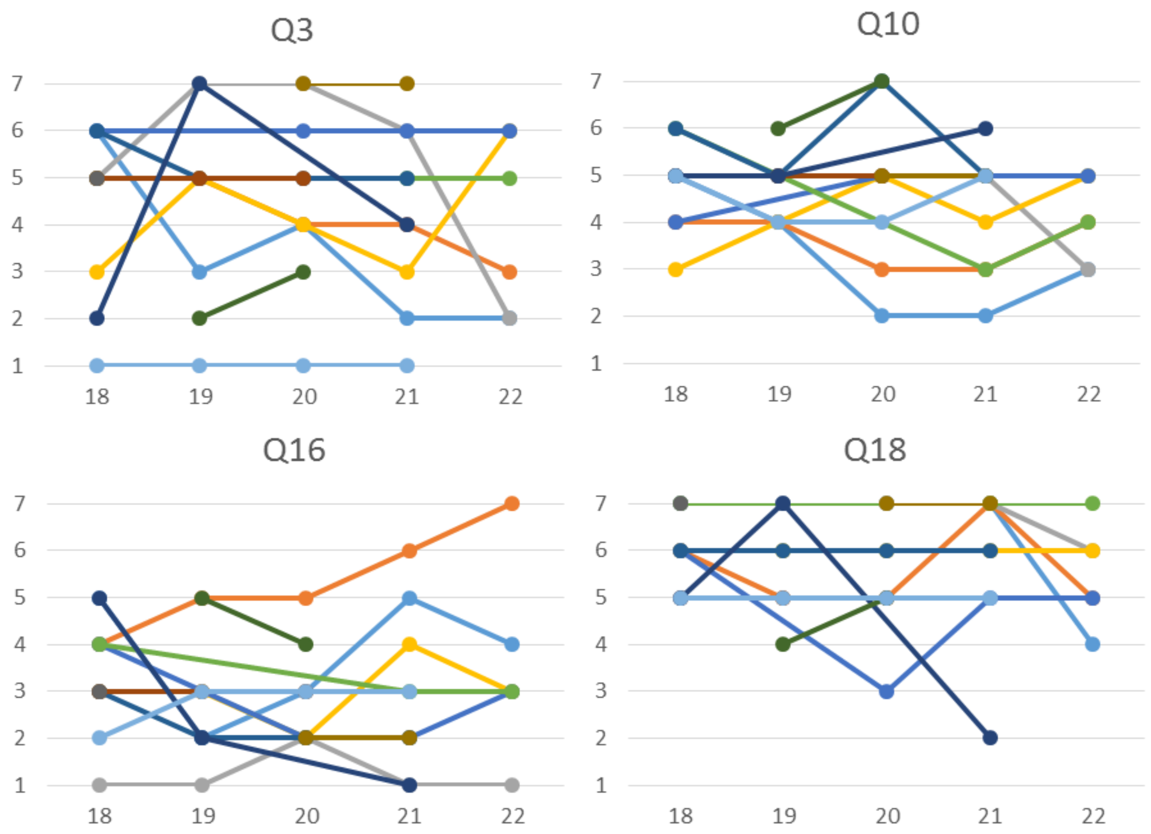

Figure 8. The daily responses for each respondent to questions rated as indeterminate (Q3, Q10, Q16 and Q18).

After alteration of the response profile for Q18, the distribution of response profiles per trait becomes as shown in Table 4. Individual adaptability is almost exclusively increasing towards the end of the exercise, whereas organizational adaptability is dominating the decreasing category.

Table 4. Final distribution of trait per response profile type.

	Response profile			
Trait	**Decreasing**	**Increasing**	**Flat**	**Indeterminate**
Organizational adaptability	Q1, Q2, Q4, Q5, Q6, Q7, Q8	-	-	Q3
Individual adaptability	Q18	Q13, Q14, Q15, Q17, Q19	-	Q16
C2 approach agility	Q11, Q12	-	Q9	Q10
Performance	Q20	-	Q21	-

Principal component analysis

The measures of sampling adequacy was initially investigated through the anti-image correlation matrix diagonals to detect the factorability of the survey items. The items *Q6*, *Q14* and *Q18* MSA less than the acceptable limit .5 and were thus excluded from the PCA. After exclusion of these items, the obtained Kaiser-Meier-Olkin measure of sampling adequacy (KMO) was .73, which was considered acceptable. Bartlett's test of sphericity χ^2 (153) = 520.49, p< .001, indicated correlations sufficiently large for principal component (PC) extraction. Five principal components with eigenvalues >1 (Kaiser's criterion) were generated which together explained 75.49 % of the variance in the data. An additional scree plot investigation showed inflexion at five components, confirming the choice of five components in the final model. The screened pattern matrix from the PCA is illustrated in Table 5, with cutoff set to .38 (roughly corresponding to 15% of the overlapping variance), suppressing any loadings below this threshold.

Table 5. The pattern matrix from the PCA with loadings weaker than .38 suppressed.

	Component				
Survey item	**1**	**2**	**3**	**4**	**5**
Q12. C2A: Possible to interact with external entities	.845				
Q20. Performance of function	.786				
Q21. Performance of TG	.751				
Q8. OA: Redundancy in function	.687	.505			
Q1. OA: Access to information about threat level	.667		.394		
Q2. OA: Access information about own situation	.557		.488		
Q15. IA: Creative problem solving	-.430				
Q19. IA: Stress		.796			
Q5. OA: Options to handle important events		-.614			
Q3. OA: Able to disseminate threat information			.968		
Q4. OA: Able to handle important events			.733		
Q7. OA: Preparations to meet unexpected events				-.837	
Q9. C2A: Allocation of decision rights				-.621	
Q17. IA: Necessary to learn new systems					.927
Q11. C2A: Possible to interact within TG					-.717
Q10. C2A: Distribution of relevant information	.462				-.494
Q13. IA: Collaboration with others	-.468				.472
Q16. IA: Uncertainty and unpredictable situations					.390
Total variance explained by component	37.56%	12.18%	10.86%	9.16%	5.72%
Accumulated variance explained by components		49.74%	60.62%	69.78%	75.49%

The component correlation matrix (Table 6) shows that all component pairs have none (|r| < .15), weak (.15 ≤ |r| < .30) or low (.30 ≤ |r| < .50) correlation. All pairs including component 4 fall into the no correlation category (|r| < .15). By contrast, the strongest component (1) has a low correlation with component 5 and weak correlation with component 3. Thus, the extracted components are fairly independent from each other.

Table 6. The component correlation matrix from the PCA.

Component	2	3	4	5
1	-.110	.231	-.137	-.381
2		-.159	-.011	.224
3			-.089	-.117
4				.122

The principal components have been listed again in Table 7, with assigned labels and a proposed division into sub-components that can help further explain their contents.

Table 7. The principal components of adaptability as measured, labelled and split into subcomponents.

#	Label	Sub-component	Content
1	C2 structure and performance	1.1. C2 interaction	Q12. C2A: Possible to interact with external units
			Q10. C2A: Distribution of relevant information
		1.2. Situation assessment	Q1. OA: Access to information about threat level
			Q2. OA: Access information about own situation
		1.3. Role importance	Q15. IA: Creative problem solving
			Q13. IA: Collaboration with others
			Q8. OA: Redundancy in function
		1.4. Performance	Q20. Performance of function
			Q21. Performance of TG
2	Mental workload	2.1. Individual stress	Q19. IA: Stress
		2.2. Organizational resilience	Q5. OA: Options to handle important events
			Q8. OA: Redundancy in function
3	Management of deviating events	3.1. Information management	Q3. OA: Able to disseminate threat information
			Q2. OA: Access information about own situation
			Q1. OA: Access to information about threat level
		3.2. Ability to act	Q4. OA: Able to handle important events
4	Planning		Q7. OA: Preparations to meet unexpected events
			Q9. C2A: Allocation of decision rights
5	Communication and individual uncertainty	5.1. Individual uncertainty	Q17. IA: Necessary to learn new systems
			Q16. IA: Uncertainty and unpredictable situations
		5.2. Communication and collaboration	Q11. C2A: Possible to interact within TG
			Q10. C2A: Distribution of relevant information
			Q13. IA: Collaboration with others

DISCUSSION

The operational circumstances around the study resulted in a slightly different exercise configuration than was originally expected. Half of the sampling opportunities and a substantial portion of the intended respondents all disappeared before the data collection could even begin and the obtained response rate was 22% of the maximum. With consideration taken to changed preconditions, the modified response rate was 71% from the remaining sample points, indicating that the challenges to collecting data in live navy exercises are generally not due unwillingness or ignorance among the participants, but rather a question of risk assessment and planning to compensate for short notice alterations of the operational setup.

Since surveys were repeated five times instead of the planned ten, the resulting granularity was only half of the initially intended thus making the analysis of the response profile error prone. Thus, there are many possible explanations for variations in the obtained results that cannot be ruled out. The approach of requesting data at the end of each shift must presumably be reconsidered in order to find an approach which generates more data.

Some other considerations regarding obtained data should also be put forward. There is no straightforward way of objectively deciding if a response profile is flat and the moving means approach must be used with caution. In addition, four of the items were classified as indeterminate as not enough data were available to explore the cause of the found variation. In addition, the scope of this study was on repeated measurement of command team members' perception of the situation. In an assessment of performance this should be complemented with other data. It is also important to note that the organizational adaptability trait in this study is limited to *Ability to detect abnormal events* and *Ability to deal with abnormal events.*

The exercise scenario was designed to progressively become more challenging, suggesting a decreased performance and adaptability over time. The timing when the Task Force changed focus of the operation into coastal defense was visible in a majority of response profiles. The responses regarding organizational adaptability also largely correspond to expectations indicating a decreased ability to detect and deal with deviations. However, responses regarding individual adaptability indicated a trend of increased ability over time. In fact, only one of the surveyed individual items showed a decreasing trend in adaptability: Q18 on physical workload. Thus, despite increased workload and decreased organizational adaptability, individual adaptability seems to increase over time. The trend for C2 Agility is less conclusive with two decreasing, one flat and one indeterminate item.

A possible explanation for the difference between individual and organizational trends might be the scenario design. Although the situation got more complex and challenging at the Task Force level, the expectations on the different roles might have become clearer. The initial unclear but less threatening situation called for the individuals to prepare and a wider set of options. As the situation became clearer they were able to focus on a few main tasks instead of having to keep a lot of doors open although the organizational level challenges was tougher. The mission command approach implemented in the Swedish Navy might accentuate this effect. Each level has a high degree of responsibility to prepare for different options detail in an uncertain situation. When the situation clarifies each level is relatively free to decide on how to act without seeking permission from higher command.

Another possible and somewhat overlapping explanation is training effect. As work procedures settles, role tasks become more routine and knowledge of details of the exercise scenario evolves even if he study design tried to addressed this issue by not collecting data during the first part of the exercise. Yet another possible explanation is respondent bias as there might be a systematic difference in how one judge the organizational ability compared to how one judge one's own abilities and challenges.

Regarding the individual trait one should differ between role demands and the individual's adaptability. In this study, the items related to individual adaptability have been used to obtain response profiles on how respondents perceived the situation. As such the obtained results reflects the different requirements on the role they had in the command team rather than individual ability to adapt. Thus, the results indicate that role requirements regarding adaptability are not constant. Instead they vary in a consistent way over time but the variation is not necessarily positively correlated to other adaptability traits.

The exploratory analysis of latent structures found five partially independent components. The strongest component, C2 structure and performance, explains more than 37% of the variance and is characterized by C2 interaction, situation assessment, role importance and performance. The component is negatively loaded by collaboration and creativity on the individual level, which is in line with the opposite trends identified between individual and organizational factors.

The second component, mental workload, contains survey items relating to individual stress and organizational resilience, with stress and redundancy as the strongest positively loading items. As in the first component, the individual adaptability item, the presence of options for choosing an action loads negatively on this PC. In addition to the previous discussion on response trends, a hypothetic explanation for this negative loading could be that the mere existence of alternatives induces stress and perceived workload.

The third component is primarily about management of deviating events, including interpreting and disseminating information about the current situation, i.e. information management and sense-making. Additionally, there is a strong loading from the TGs ability of handling important events relating to current threats.

The fourth component is planning oriented, with loadings from allocation of decision rights and preparations for unexpected events. Since this component does not correlate with any of the other components it appears to have had little impact on adaptability and performance as a whole. This result may seem somewhat counter-intuitive, however, allocation of decision right and preparedness to meet unexpected events may still have an effect on performance in the longer perspective. A variation which was not captured in this data collection. Further, it may have been difficult for the respondents to reflect upon these questions in a valid way. For example, rating one's preparedness to unforeseen events requires a way to imagine these unexpected events, which is mentally challenging.

CONCLUSION

With the presented study we have explored how adaptability in a C2 system can be measured and related to performance. Due a cumbersome work environment, force majeure, and absence of on-site researchers, the response rate for the self-assessment reports did not meet initial expectations. Still, the response rate from the remaining possible dataset suggests that repeated self-assessment surveys are feasible for data collection in the context of distributed exercises. An appropriate approach to obtain more data must be developed together with the navy to compensate for operational circumstances.

Through explorative analysis, a systematic difference was detected in how the respondents answered questions regarding individual adaptability versus organizational adaptability. The trend regarding C2 agility is less clear with two decreasing, one flat and one indeterminate item. This is consequently perhaps the most interesting outcome from the study. We have not been able to identify other studies reporting results on this topic and thus call for further investigation.

A PCA confirmed the existence of latent structures in the dataset, allowing us to cluster variables based on correlations. Five clusters have been identified, suggesting that communication and handling of deviating events can be directly linked to how the respondents assess their own performance. The relative importance of these components should be further investigated.

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A tool to quickly increase knowledge for effective coordination in crises

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ABSTRACT

In complex crises, coordination between organizations is challenging. Knowledge needed to coordinate, like responsibilities, capabilities and interdependencies between tasks are often not known or not communicated systematically. As a result, coordination develops gradually and causes confusion. In this paper we describe an approach and tool called 'Profiler', that focuses on quickly increasing knowledge and understanding about the participating organizations while preparing for, or at the beginning of a crisis. Profiler was evaluated during an exercise of 1 Civil Military Coordination Battalion (1CIMICbat). Teams consisting of functional specialists performed a damage and needs assessments after a flooding. The results show that participants that used Profiler increased their knowledge and integrated understanding, when this was initially lacking. Further, participants with improved knowledge and integrated understanding, coordinated more within and between teams, when they perceived to be interdependent. Our results point in the direction that coordination effectiveness and efficiency may be improved with our approach.

Keywords

Coordination, collaboration, team knowledge, integrated understanding, preparation

INTRODUCTION

Complex crisis situations affect the responsibilities of multiple organizations, such as governmental departments, first responders and organizations responsible for critical infrastructure. The needs created by large disasters require extensive coordination, collaboration and communication between these organizations (Kapucu, 2003; Kapucu & Van Wart, 2006; Kapucu & Garayev, 2011). Disaster response needs structure and processes on the one hand and adaptability and improvisation on the other hand (Harrald, 2006). When dependencies between tasks are known and predictable, the most efficient mode of coordination is through a prescribed action plan, which directs the choices of actions at a given situation. But as disasters are characterized by a high level of contingency, actions and responsibilities of actors often cannot be pre-determined in detail. Mutual adjustment of activities is required in ad hoc organizational networks. Unified command brings together the "commanders" or "liaisons" of major organizations involved in the incident in order to coordinate an effective response. It provides a forum for this team of liaisons for identifying critical events and actions and allows mutual adjustment for changing dependency relations. Post-disaster crisis reports (e.g. IOOV, 2011) have consistently shown that coordination breakdown is one of the core reasons for ineffective crisis response (DeChurch and Mathieu, 2009).

Coordination is often supported by information systems. “Coordination by awareness” has become a promising trend of coordination technology in emergency response activities (Gonzalez 2008; Faraj & Xiao 2006). The idea is to provide awareness of critical events, each other’s activities and to give insight in roles and responsibilities of participating organizations (Way & Yuan, 2012; Yu & Cai, 2012). The effective use of information from these systems for coordination requires knowledge about each other’s capabilities and collective task. It is doubtful that coordination will take place among organizations or team members if they are unaware of each other or each other’s capabilities (McGuire, 2009). The organizations involved in ad hoc organizational networks often lack a shared history of working together and do not know each other’s expertise or how to integrate their tasks. Such common ground is needed for efficient and effective coordination. Getting to know each other takes time, which is often not available in times of crisis. As a result, coordination and collaboration develops only gradually and remains limited which often leads to confusion and misunderstanding. It is therefore important to develop effective and efficient tools and approaches to support knowledge-sharing for effective and efficient coordination in ad hoc organizational networks. Prior team research has mostly focused on social and cognitive mechanisms for effective coordination. Practical interventions to increase knowledge and understanding are largely missing. The goal is to help emergency managers and their partners to gain knowledge and understanding of other participants' capabilities in a clearly specified and systematic manner. A solution is needed to support organizations in a crisis to quickly and effectively share knowledge about each other and about their task dependencies in the early stage of their collaborative efforts. We developed an approach and a tool that focuses on quickly increasing knowledge and understanding about the participating organizations.

Three questions in the development of this approach and the tool were:

1. What are the key coordination constructs for (ad hoc) effective coordination?
2. What specific knowledge needs to be shared between teams from multiple organizations?
3. How can this knowledge quickly and effectively be exchanged?

In the following paragraphs we will address these questions.

The Key Constructs

Any group of partners faced with accomplishing a complex task has to resolve two issues: Who is doing what, and how to coordinate their efforts. Coordination is the activity of managing interdependencies between tasks performed by different actors (Malone & Crowston, 1994). Three kinds of interdependencies can be distinguished: outcome, process and input interdependencies (DeChurch & Mathieu, 2009). Input interdependence refers to the extent to which inputs must be shared to achieve goals (e.g. like people, expertise, resources or information). Process interdependence refers to the extent to which interaction and integration between tasks is required. Outcome interdependence refers to the extent to which the costs and benefits received by actors, depend on successful performance of others. When there are no dependencies between the tasks of team members or teams, or when none are perceived, there is no task-oriented reason to coordinate and communicate (Zhang, Hempel, Han & Tjosvold, 2007). According to Parker & Axtell (2001), coordination is more effective when members have an integrated understanding, meaning that the members understand how their tasks relate to the tasks of others. Integrated understanding improves perspective taking, adopting the viewpoint of those that depend on you and vice versa (Parker & Axtell, 2001). The development of integrated understanding of their interdependencies is expected to improve the coordination between the collaborating teams from multiple organizations.

DeChurch & Mesmer-Magnus (2010) found for team effectiveness, in a meta study, that team knowledge (i.e. knowledge about who knows what), task knowledge (i.e. knowledge about tasks and responsibilities) and transactive memory systems (i.e. shared understanding of who knows what in the group) explains effective and efficient coordination in high performing teams. According to Brandon and Hollingshead (2004) team knowledge consists of task-expertise-person combinations of others (TEP) in their memory. The recognition of and access to available expertise based on this team knowledge is useful for coordination: allocating tasks, finding information, giving and taking advice and involving each other in activities (Faraj & Sproull, 2000; Moreland, 1999). Transactive memory is a mechanism used to explain how individuals in teams rely upon each other for encoding, storing, and retrieving information about different domains (Ren & Argote, 2011).

According to Wegner, Giuliano and Hertel (1985) transactive memory consists of two elements: knowledge in the memory of the team members and the coordination and communication processes between these team members. Team members rely on one another to be responsible for specific expertise such that collectively they possess all expertise and information that is needed (Lewis, 2003).

When coordination is required between teams from multiple organizations, not only knowledge about the tasks and expertise of own team members is needed, but also knowledge about the tasks and expertise of other teams. Access to this knowledge is especially important in environments in which tasks and team members change dynamically (Ren, Carley, & Argote, 2006).

In sum, increasing team knowledge (tasks and expertise of own team and other teams) and integrated understanding (interdependence of tasks) is expected to improve coordination between the collaborating partners.

What Specific Knowledge Needs to be Shared?

Based on the literature described above, we formulated a set of items that should be addressed for improving coordination between different organizations: understanding tasks, expertise and responsibility. The question is what specific knowledge is needed to be shared between teams of different organizations.

A workshop with collaboration building experts and didactical experts from TNO[1], generated fifteen critical topics that are important to know about each other when working together. A guiding question during the workshop was "What do you need to know about each other before starting to work together?". This resulted in a mindmap with general topics (i.e. 'background', 'capabilities', 'dependencies' etc.), that was further detailed in subcategories. For example, the general topic capability can be further divided into e.g. expertise, resources etc. In addition, it was stressed that depending on the context of collaboration (e.g. time pressure, duration of collaboration, domain) different information is important to know about each other. There is a difference between a project team that will work together for a year, and a crisis management team that only works together for a short period under high time pressure. When planning to work together for a longer period of time other information might be more relevant to share compared to working together only for a limited period of time. In the latter situation sharing 'need to know' information might be more relevant than 'nice to share' information.

We evaluated this list of topics with potential (military) users, using a critical case from their operational experience. We gave the interviewees a set of cards with the different topics from the workshop, which they had to order for their case in terms of importance/priority. Based on the results of the workshop and of the interview sessions, we selected the six most important topics (see table 1).

Table 1 Six selected topics

Responsibility & authority (i.e. "my organization acts when…")
Interests (i.e. "my personal interest in this scenario is…")
Identification (i.e. "you can best reach me by….")
Tasks (i.e. "the tasks and roles of my organization in this scenario are…")
Resources (i.e. "my organization has the following means available")
Knowledge & Skills (i.e. "I have the following skills, expertise and experience")

From the workshop and the interview sessions it became also clear that a distinction should be made between the person at the table and the organization they represent. Organizations and what they mainly do is more general information and might not (fully) reflect the knowledge an individual might bring to the table.

How to Exchange and Increase Knowledge About Each Other

We have now two clear criteria for the tool to support. The tool should address increasing team knowledge and

[1] A Dutch research company

integrated understanding, and the tool should address knowledge about the person experience and expertise, and the organization he or she represents. The third criterion relates to the way this knowledge is increased.

Multiple studies have shown that team members that train together improve their coordination and communication processes and knowledge of each other (Liang, Moreland, & Argote, 1995; Moreland, Argote, & Krishnan, 1998). Simply exchanging this information does not automatically mean that people internalize, or remember, the information. Therefore a game-element should be added by which participants are invited to share, encode and retrieve knowledge, learn from each other and negotiate on how to work together (Gabelica, van den Bossche, Fiore, Segers & Gijselaers, 2016). A problem with standard training or exercises is that they are usually time consuming, especially when different organizations are involved. The goal of the tool is to support increasing knowledge about each other in a short time-frame.

Description of a Tool to Improve Coordination: Profiler

Based on these three criteria we developed an approach and a paper-based tool to improve coordination, which we called ‘Profiler’. The process is as follows: For a scenario related to the domain of activities the organizations usually work in, e.g. handling a flooding, participants fill in an individual profile and an organizational profile. After these profiles are filled in, the participants can see the information on the various topics that the other participants have provided. In a collective session active sharing of information is stimulated by using a set of dilemma cards. These dilemma cards challenge the team to decide which team member(s) should be involved to solve the various dilemmas, or problems, based on what they have shared in the introductory round and on their profile cards. An example of one such dilemma is, for instance, “the flooding water is threatening the local art museum and its treasures. Action must be taken to save hundreds of rare art pieces and time is critical. Who in this group would you involve to tackle this dilemma and why?”. In this way, the team members actively use the information that was filled in. The Profiler intervention lasts about 120 minutes. See table 2 for a detailed description of the different steps. The different steps should be guided by a facilitator.

Table 2 Description of Profiler

Profiler Step-by-step
Step 1: Explanation goal Profiler and set-up session. Goal of Profiler is to get to know each other and each other’s expertise in a short time-frame.
Step 2 Selection of topics. During this step, team members discuss what topics they want to discuss in order to learn more about each other. The team has to reach consensus and select three topics from the six topics listed in table 1.
Step 3 Filling out the profiles. Team members will fill out their profile for the selected topics. Some guidelines: -Use only relevant information; information has to be specific for the context of collaboration -Make sure that somebody who does not know you, is able to understand your card.
Step 4 Short exchange and explanation of the information. The team members shortly exchange and explain the information they have written down on their profile; both their personal profile and the organization profile.
Step 5 Intervention. For each dilemma (corresponding to the selected topics) the group must decide what organization should be involved to tackle the problem. After establishing this, the group must decide which people from that organization within their team are most suitable. All dilemmas are discussed by the group. If the discussion does not lead to anything or does not contribute to the intervention, the trainer can put it to a halt.
Step 6 Prioritization. Step 6 is an optional step that can be in- or excluded. This step is to challenge the participants and to stimulate discussion. During this short discussion, the group must decide what dilemma deserves their first attention, second, etc., etc.
Step 7 Reflection. Team members will reflect on the previous steps. They can use different questions that we have described (e.g.

'what did you learn about the other organizations and team members', 'how is this of use for your work').
Step 8 Formulate work agreements. The group formulates work agreements according to which they will work in the future. They can use the information from the profiles, and the discussion during the session.

EVALUATION OF PROFILER

The general idea is that Profiler improves knowledge about team members and other teams concerning the attributes previously described (i.e. improves team knowledge) and Profiler improves knowledge about how tasks relate to each other (i.e. improves integrated understanding). Profiler does so when team knowledge and integrated understanding is initially insufficient. This subsequently improved 'team knowledge' and 'integrated understanding' in turn increases coordination within and between teams, when interdependencies are perceived within and between these teams. Coordination is not increased when no interdependencies are perceived. The model describing the Profiler value chain is graphically represented below.

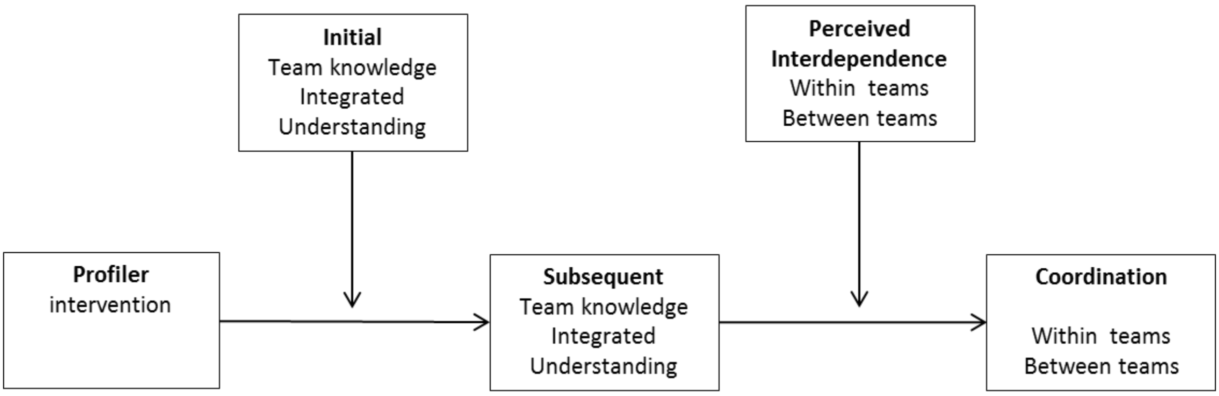

Figure 1 Model of Profiler value chain

From this model the following hypotheses are derived:

Hypothesis 1: Profiler increases team knowledge and integrated understanding when initial team knowledge and integrated understanding is low.

Hypothesis 2: team members with more team knowledge and integrated understanding coordinate more within and between teams, when they perceive to be interdependent.

To prove the practical relevance of Profiler we evaluated Profiler during a military exercise in October 2012. This exercise *Borculo*[2] takes place once every year and its main training goal is civil-military cooperation. Over the years, Borculo has evolved into a 2,5 day scenario-based exercise of which the overall theme differs per year. The unit training in this exercise is the so-called 1CIMIC battalion[3] (1CIMICbat), a unit composed of mainly reservists. All these reservists are employed part-time by the Netherlands Armed Forces because of their specific (civil) expertise. This concerns expertise that the Netherlands Armed Forces does not have, or has too little of available. Within 1CIMICbat, the so-called functional specialists are part of one of the six networks: Humanitarian Affairs; Civil Administration; Civil Infrastructure; Integrated Development Entrepreneurial Activities; Economy & Employment and Cultural Affairs & Education[4], depending on the reservist's

[2] Borculo refers to the little town in the North of the Netherlands where the first of the series of this exercises took place. Other venues of the exercise have been –amongst others- Rotterdam, Amsterdam and Utrecht. The name Borculo is maintained, referring to the place of origin.
[3] In 2013 1CIMICbatallion ceased to exist and was turned into 1CMIco (1 Civil-Military Interaction Command). Because this case was tested when 1CIMICbat was still functional, we will describe the old situation, fully aware of the new situation.
[4] In the current set-up these 6 networks have been replaced for new networks, based on the PMESI-factors – Political – Military – Economic – Social - Infrastructure

background.

Method

Participants

About 150 participants joined the overall exercise. Of these 150 participants about 120 were functional specialists (reservists) from one of the networks as described above, the others were part of the exercise staff or the permanent staff of the battalion. The reservists worked together in teams of about six members. Most team members did not know each other beforehand and the teams were randomly composed by the permanent military staff of 1CIMICbat. Experience within the teams differed: some reservists had more experience (exercise experience but also mission experience) than others; experience that is reflected in the military ranks; varying from first lieutenants to lieutenants-colonels.

Task

The exercise was focused on drawing up an advice for the reconstruction of, and by, civil authorities of the city of Rotterdam after a devastating flooding. The teams were composed of reservists of the different networks. All these teams contributed to an assessment in order to inform their commander on the current situation in the scenario-reality. To collect this information, the teams visited different role-players (e.g. representative from the community, or the water board) that provided them with vital information for their assessment.

Procedure

The battalion's commander and the exercise staff approved the pilot. During the first day of the exercise we applied Profiler. Before the start and at the end of the day, we asked all participants in the exercise to fill out the questionnaire. Six teams participated in the Profiler-session. These teams were randomly assigned by the exercise staff. At the start of the first exercise-day, instead of visiting one of the role-players, these teams joined our session. They were informed that their participation was voluntarily and that they could stop anytime. They were all willing to participate and there was nobody in the exercise that refused to participate in the pilot. We introduced Profiler, its goals and its working to these functional specialists. Afterwards, they followed the steps of Profiler, as described in table 2. The total session lasted 120 minutes.

Measurements

Respondents

59 participants (49%) filled out the questionnaire before the start and at the end of the day. Of these respondents 23 participated in the Profiler session (39%), the other 36 respondents (61%) were the control group. We did not ask questions about demographics to ensure the anonymity of the participants, which is very important when using military personnel as a target audience. Moreover, the demographic information was not relevant for our analysis.

Team knowledge & integrated understanding

We used four items from Parker and Axtell's (2001) integrated understanding scale to measure this construct. Specifically, we asked participants to rate the degree to which they understood various aspects of their work on a 7-point scale (1 = completely disagree ~ 7 = completely agree). Items had the stem of "I understand how my work contributes to the decision-making of the commanding officer" and "I understand how my work affects the work of other groups in the collaboration." We supplemented these items using six items of the 'expertise location scale' from Faraj & Sproull (2000) to measure team knowledge. We asked participants to indicate to what extent they agreed with statements such as "I know which person I should approach for specialist knowledge and know-how", using again a 7-point scale (1 = completely disagree ~ 7 = completely agree). We administered these items before and after the first day of the exercise. We then calculated participants' initial (pre-exercise) 'team knowledge and integrated understanding' and subsequent (post-exercise) 'team knowledge and integrated understanding'. The combined 10-item scale reliably captured members' initial (Cronbach's alpha = .90) and subsequent levels of 'team knowledge and integrated understanding' (Cronbach's alpha = .87). See Appendix A for all scale items.

Perceived task interdependence

We adapted four items from van der Vegt, van de Vliert, and Oosterhof's (2003) task interdependence measure to capture this construct. The items were adapted so that they captured both participants' task dependence on colleagues within and outside their team. Specifically, we used items such as: "In order to complete my work, my fellow team members and I have to exchange information and advice." and "I had to work closely with other teams to do my work properly" (1 = "completely disagree" to 7 = "completely agree"). Cronbach's alpha was

.71. We administered these items at the end of the first day of the exercise. See Appendix A for all scale items.

Coordination

We captured participants' coordination with 11 items from Ancona and Caldwell's (1992) boundary-spanning scale. Items were adapted so that they captured coordination within teams (i.e., between the respondent and his or her team members), as well as coordination between teams (i.e., between the respondent and members from other teams). Respondents were, for example, asked to report how often they "coordinated work with your fellow team members," "resolved problems with your fellow team members," "collected information/ideas from members of other teams," "procured information and resources from other teams," and "scanned their external environment for information and expertise" on a 5-point scale (1 = Never ~ 5 = Very frequently). We administrated these items at the end of the first day of the exercise. Cronbach's alpha was .72. See Appendix A for all scale items.

Feedback of participants

At the end of the session we had a short discussion with the participants to provide us with feedback about Profiler.

RESULTS

Table 3 depicts means, standard deviations, and bivariate correlations for all variables. The associations of the profiler intervention with subsequent team knowledge and understanding (r = -.06, n.s.) and coordination within and between teams (r = -.18, n.s.) were non-significant, underlining the potential relevance of considering moderating factors for these relationships.

Table 3 Descriptive Statistics

			r			
Variables	*M*	*SD*	1	2	3	4
1 Profiler intervention	.39	.49				
2 Initial team knowledge & integrated understanding	4.72	1.14	-.02			
3 Subsequent team knowledge & integrated understanding	5.18	.83	-.06	.39**		
4 Perceived interdependence within and between teams	4.16	.96	.12	.00	.17	
5 Coordination within and between teams	2.48	.59	-.18	.14	.26**	.42**

Note: N = 43 to 59 due to missing values; * $p < .05$; ** $p < .01$

Hypothesis 1 predicted that initial 'team knowledge and integrated understanding' moderates the relationship between participation in Profiler sessions and subsequent 'team knowledge and integrated understanding'. We conducted a hierarchical multiple regression to test for this relationship. In the first step we regressed subsequent 'team knowledge and integrated understanding' on participation in Profiler sessions and initial 'team knowledge and integrated understanding'. Next, we included the multiplicative term "participation in profiler × initial 'team knowledge and integrated understanding' in the regression equation. The multiplicative term reached significance (B = −.65, SE = .23, $p < .007$), thereby indicating that participants' initial 'team knowledge and integrated understanding' moderates the relationship between participation in Profiler sessions and subsequent integrated understanding (see Table 4). Additional simple slope analyses indicate that participation in Profiler is positively related to subsequent 'team knowledge and integrated understanding' when initial 'team knowledge and integrated understanding' is lower (simple slope at −1SD: B = .52, SE = .31, $p < .098$; see Aiken & West, 1991), but negatively when initial 'team knowledge and integrated understanding' is higher (simple slope at +1SD: B = -.78, SE = .35, $p < .031$). The result that participation in Profiler is positively related to subsequent 'team knowledge and integrated understanding' when initial 'team knowledge and integrated understanding' is lower, points in the direction of our hypothesis. This result is marginally significant (p <.10). The negative relation when initial 'team knowledge and integrated understanding' is higher, is remarkable and wasn't expected.

Table 4 Regression Estimates for subsequent team knowledge & integrated understanding

	Model 1	Model 2
Intercept	5.27 (.17)**	5.29 (.15)**
Profiler intervention (PI)	-.05 (.26)	-.13 (.24)
Initial team knowledge & integrated understanding (IKU)	.33 (.12)*	.60 (.15)**
PI × IKU		-.65 (.23)**
Adjusted R-Square	.11*	.26**
Delta R-Square		.15**

Note: N = 43 due to missing values; * $p < .05$; ** $p < .01$

Hypothesis 2 posited that perceived interdependence moderated the relationship between participants' subsequent integrated 'team knowledge and integrated understanding' and coordination. As expected, we find a significant interaction coefficient for subsequent 'team knowledge and integrated understanding' × perceived interdependence ($B = .17$, $SE = .07$, $p < .019$; see Table 5). Simple slope analyses indicate that subsequent 'team knowledge and integrated understanding' positively related to coordination when perceived interdependence was higher (simple slope at +1SD: $B = .32$, SE = .11, $p < .005$), but not when interdependence was lower (simple slope at −1SD: $B = -.01$, SE = .09, .869, *n.s.*). Hence, we find support for our second hypothesis.
The participants were enthusiastic about the way Profiler works: getting to know each other in a more dynamic way than a standard introduction round. Also, they usually don't take time for this during an exercise. They explained that it helps them to know where to find certain expertise. Furthermore, it gave them a broader perspective and more integrated view about the different networks. Some people mentioned that the case we used could be improved.

Table 5 Regression Estimates for coordination within and between teams

	Model 1	Model 2
Intercept	2.57 (.09)**	2.55 (.09)**
Profiler intervention	-.21 (.14)	-.25 (.14)
Subsequent team knowledge & integrated understanding (SKU)	.11 (.07)	.16 (.07)
Perceived interdependence within and between teams (PID)	.21 (.07)**	.21 (.07)**
SKU × PID		.17 (.07)*
Adjusted R-Square	.17**	.24**
Delta R-Square		.07*

Note: N = 59; * $p < .05$; ** $p < .01$

CONCLUSIONS

The results support the hypothesis that Profiler increases 'team knowledge and integrated understanding' when initial 'team knowledge and integrated understanding' is low (hypothesis 1). This implies that Profiler has the most value when participants do not know each other very well (i.e. team knowledge and integrated understanding) and has less value when they do. Surprisingly, when initial 'team knowledge and integrated understanding' was higher, participation in Profiler is negatively related to subsequent 'team knowledge and integrated understanding'. This implies a decrease in 'team knowledge and integrated understanding' which is unlikely. The measurements were subjective. A possible explanation is that this group initially overestimated their knowledge and that participation in the Profiler session made them more aware of their actual level of 'team knowledge and integrated understanding'.

The results also indicate that team members with more 'team knowledge and integrated understanding' coordinate more within and between teams, when they perceive to be interdependent (hypothesis 2). When perceived interdependence is low, they do not coordinate more. This is understandable because coordination does not improve task performance when tasks are not perceived to be interdependent. It seems that with 'team knowledge and integrated understanding' coordination is efficient and effective. Therefore we conclude that it is important to pay attention to increase this knowledge in the preparation and response phases of crisis management. Profiler seems an approach to achieve this in a short time frame.

The results of our pilot showed that not only coordination within teams improved but also between teams. Even though participants only performed the Profiler session with their own team, during this session they also increased their knowledge about the networks at a more general level. This can be explained because during the session they shared their individual profiles and their network profiles (organizational profile). This way, they knew better when to inform, involve or coordinate with other networks as well.

We expect that more efficient and effective coordination eventually leads to more synergy and less conflicts between organizations managing the effects of a crisis.

When using a paper-based version of Profiler, team members have to fill out the profiles during the session. This takes up a lot of time. When Profiler would be available as a digital tool, profiles could be filled out dislocated. Another added value is that it is possible to meet your team members before the actual meeting. It saves time during the meeting to make a digital acquaintance with your team members before the actual meeting. Moreover, the digital version of Profiler enables team members to access the information on the profiles whenever needed. It also facilitates changes in the composition of the team; when one team member is replaced by a new team member, he or she can start by learning all about the other organizations and team members by using the Profiler digital tool.

We applied Profiler in only one context, civil-military cooperation, with a specific group of participants. The generalization of these results to other situations is therefore limited. To show the added value of Profiler in different contexts, Profiler should be applied and evaluated in another context as well.

Profiler can be used to prepare crisis managers for different types of scenario's. Crisis management teams are ad hoc teams that differ depending on the type of crisis and depending on who is on duty at that time. Therefore it seems less relevant to increase knowledge on personal level in advance. However, i knowledge about the organizations involved is still useful and can be done in advance for different types of scenarios.

Profiler might also be useful in the response phase, mainly for situations when there is more time (e.g. extreme weather, flooding). In this situations it might be possible to fill in digital profiles of the team members and organizations involved. This way, team members are able to fill out and share their profiles before their first crisis team meeting.

FUTURE RESEARCH

The previous years we have been working on a digital version of Profiler. A demo version is ready. Figure 2 gives an impression of the digital Profiler tool. With this digital tool it is possible to fill out the profiles dislocated. Also it is possible to browse the profiles and to search for specific topics of interest. Another extra functionality called 'Mix & Match presents profiles that might be of interest to the user.

Profiler is part of iCOBUS, an 'intelligent Collaboration Building Suite' – an integrated concept of tools for developing effective collaboration (Kamphuis et al., 2013). Profiler is one of the tools incorporated in a demo version of iCOBUS that we recently worked on. In future research we would like to evaluate the current digital tools.

Conducting another experiment where we compare our tool with an existing tool would be interesting for future research. This way we can test the added value of Profiler. Also it is interesting to investigate our explanation for the negative relation between higher initial team knowledge and participation in Profiler. This explanation could be tested more deeply in future research.

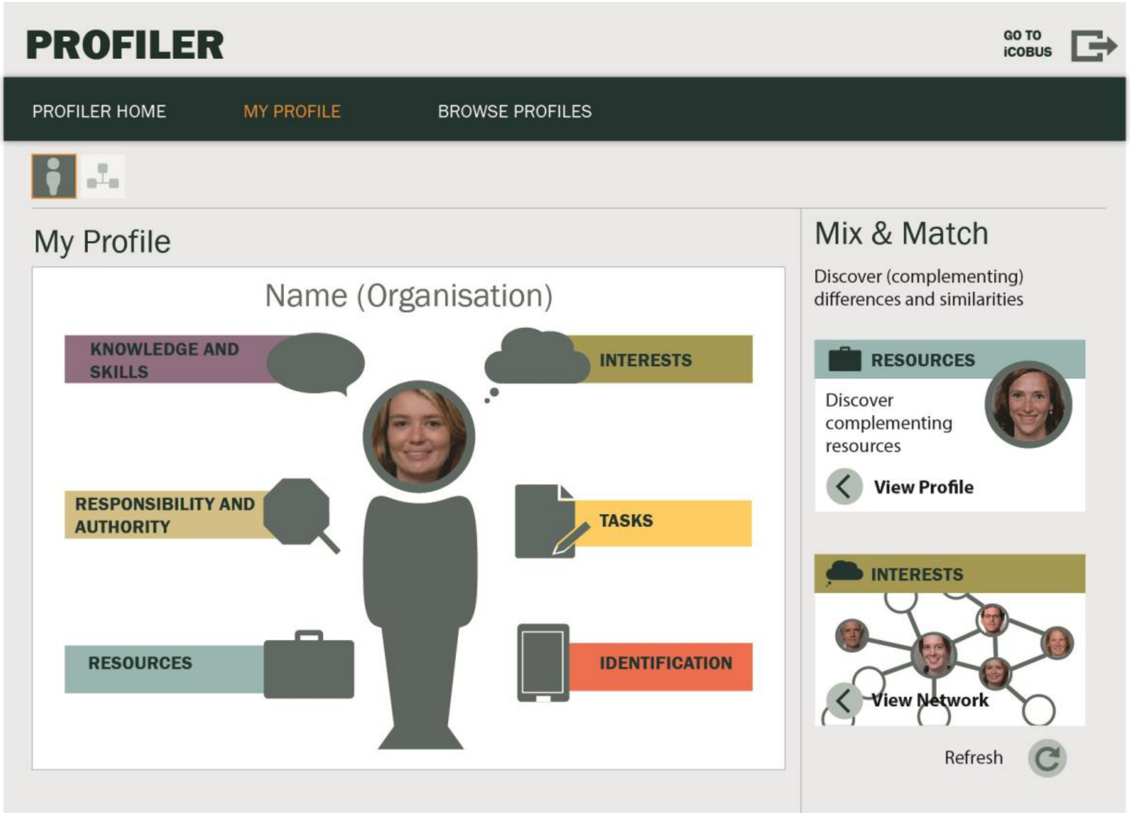

Figure 2 Screenshot Profiler (digital tool)

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Appendix A – Survey items

Scale	**Item**	**Cronbach's alpha**
Team knowledge & integrated understanding	I understand how my work contributes to the decision-making of the commanding officer.[a]	.90 (pre survey) .87 (post survey)
	I understand how my work affects the work of other groups in the collaboration. [a]	
	I understand how the collaboration works as a whole. [a]	
	I understand the jobs of the people I pass work to. [a]	
	I know which fellow team member I should approach for specialist knowledge and know-how. [b]	
	I know which what task-related skills and knowledge my team members possess. [b]	
	I know which member in the collaboration I should approach for specialist knowledge and know-how. [b]	
	Team members know what task-related skills and knowledge they each possess. [b]	
	The team has a good "map" of each others' talents and skills. [b]	
	Team members are assigned to tasks commensurate with their task-relevant knowledge and skill. [b]	
Perceived task interdependence	I have a one-person job; I rarely have to check or work with my fellow team members (re- versed). [c]	.71
	I have to work closely with my fellow team members to do my work properly. [c]	
	In order to complete my work, my fellow team members and I have to exchange information and advice. [c]	
	I have a one-person job; I rarely have to check or work with <u>other</u> teams (re- versed). [c]	
	I have to work closely with <u>other</u> teams to do my work properly. [c]	
	In order to complete my work, <u>other</u> teams and I have to exchange information and advice. [c]	
Coordination within and between teams	How often have you… …coordinated work with your fellow team members. [d]	.72
	…resolved problems with your fellow team members. [d]	
	…collected information/ideas from your fellow team members. [d]	
	…procured information and resources from your fellow team members. [d]	
	…scanned your team for information and expertise. [d]	
	…resolve coordination issues with members of <u>other</u> teams.	

	…coordinated work with from members of other teams. [d]	
	…resolved problems with members of other teams. [d]	
	…collected information/ideas from members of other teams. [d]	
	…procured information and resources from members of other teams. [d]	
	…scanned their external environment for information and expertise. [d]	

a = based on Parker and Axtell's (2001) integrated understanding scale; b = based on the expertise location scale from Faraj & Sproull (2000); c = based on from van der Vegt, van de Vliert, and Oosterhof's (2003) task interdependence measure; d = based on Ancona and Caldwell's (1992) task-coordinator boundary-spanning scale.

A Meta-theory of Command & Control in Emergency Management

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ABSTRACT

This paper presents work in progress on developing a meta-theory of C2 in emergency management. Most research in C2 focuses just on one or two scientific disciplines. Just one paper has been found that gives a systematic overview of the science of C2.

The approach taken employs entity-relationship modelling, yielding a set of scientific disciplines. These disciplines are compared with five military C2 doctrine publications. Doctrine found in at least four publications corresponded to the disciplines of decision theory, leadership theory, organizational theory, psychology, and the degree of delegation. Some topics not covered by the disciplines were found, indicating that analysis should be extended to C2 processes, resilience, and agility, permitting the development of guidance for practitioners. Further work is needed to compare the disciplines with civilian doctrine. Moreover, the disciplines could be compared to ICCRTS and ISCRAM conference proceedings, yielding an assessment of the maturity of C2 research.

Keywords

Command and control, doctrine, meta-theory, scientific discipline, entity-relationship modelling.

INTRODUCTION

Command & Control (C2) is seminally defined as “the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission” (JP1-02, 2016). The overwhelming majority of the C2 literature is to be found in the military domain. As ISCRAM’s C2 Studies track shows, C2 is also an essential element of emergency management (EM). Other application domains share ideas with C2, but give it another name, e.g. mission control in spacecraft operations, traffic control or traffic management in transport and logistics, operations management in business, process control in industry, etc.

C2 is a multi-disciplinary field, with a history going back hundreds of years. Much of the C2 literature takes the form of doctrine, recording practitioner knowledge. Even though technology has been used in C2 since the late 1800s (e.g. the telegraph), the scientific literature on C2 only emerged from World War II onwards. After the advent of digital computing in the 1940s, the initial emphasis was on electrical and electronic engineering and on the fledgling information theory (e.g. coding, bandwidth, noise and distortion). This was followed by a focus on decision theory and cybernetics, then on human factors and cognitive psychology, with network theory being added most recently.

The question that this paper addresses is: which scientific disciplines are relevant to C2? Finding an answer to this question is not just important to the C2 Studies track, but has consequences for research and practice in EM and the other domains. Armed with the knowledge of which disciplines are relevant to C2, research groups could make well-founded choices on their research programmes. Cross-disciplinary research questions, such as how culture influences the design and use of C2 systems, would be easier to identify. At present, it is common to focus on one or two aspects of C2 (typically technology and/or the cognitive task), at the expense of the rest. For practitioners, knowledge of the relevant disciplines would allow their training to balance all aspects, preparing them to better handle real emergencies.

There have been some attempts to approach C2 from a multi-disciplinary viewpoint. An example in scientific research is to regard a C2 system as a socio-technical system (Walker, Stanton, Salmon & Jenkins, 2009), integrating technical choices with their social effects and vice versa. The practitioners’ world offers another example in the form of NATO doctrine, where the abbreviation DOTMLPFI – standing for Doctrine, Operations, Training and education, Materiel (i.e. equipment), Logistics, Personnel, Facilities (i.e. buildings and infrastructure), and Information – is used as a mnemonic to guide C2 system design, planning, and operations (NATO, 2009). However, none of these attempts have been systematic, leaving open the possibility that some disciplines may have been under- or over-emphasized.

This paper takes the approach that a meta-theory of C2 is needed. A meta-theory is a theory about theories. The ISCRAM 2017 CFP provides an example meta-theory for EM (see Figure 1), albeit for information systems in general. The purpose of this paper is to propose a meta-theory that determines which scientific disciplines are specific to C2. The meta-theory is constructed systematically from the definition of C2, from the relevant literature on C2 science, and from a small-scale, but realistic EM scenario (given in Section 2). Entity-relationship modelling (Chen, 1976) provides the formal basis. First, the entity-classes involved and the relationships between them are identified in Section 3. Then the scientific disciplines associated with the entity-classes and relationships are identified in Section 4. To test the meta-theory, it is compared with C2 doctrine (in Section 5). Finally, conclusions are drawn and further work identified in Section 6.

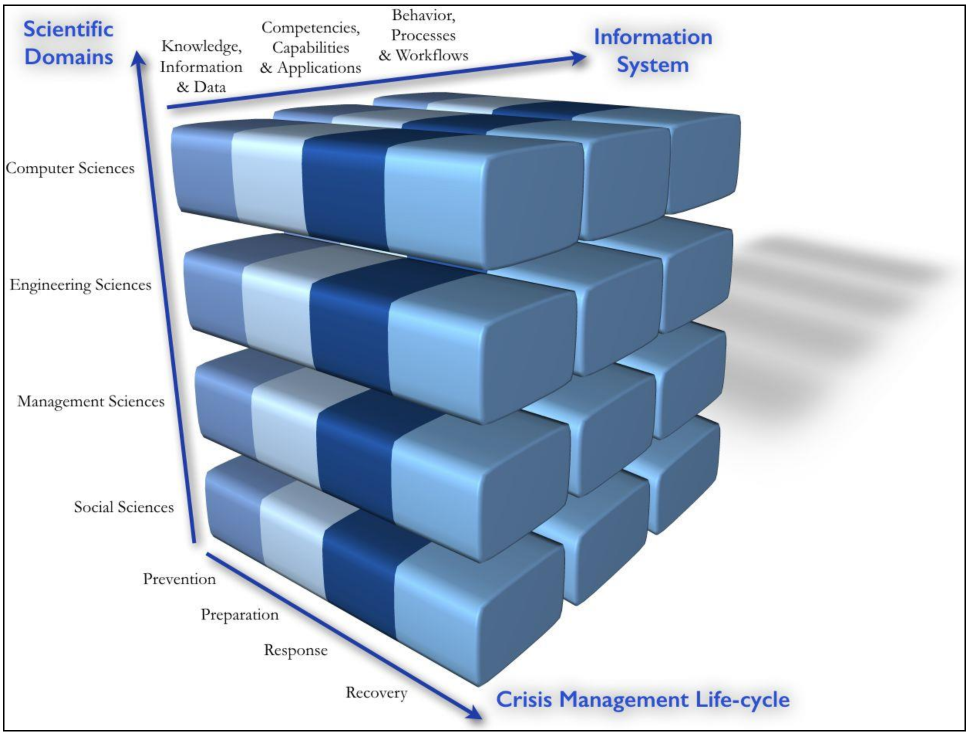

Figure 1. Example meta-theory from ISCRAM 2017 CFP.

DEFINITION, LITERATURE AND SCENARIOS

Definition

The definition of C2 given in the Introduction is drawn from the military literature. To increase its relevance to EM and to simplify the task of identifying scientific disciplines, this definition is modified slightly. The term "resources" will be used instead of "forces", and the distinction between assignment and attachment of resources will be relaxed. The term "commander" is retained, even though some organizations prefer "leader" or "manager", because the term is recognized in the EM literature, e.g. in "on-site commander" and "incident commander". In this paper, therefore, C2 will be defined as "the exercise of authority by a properly designated commander over assigned resources in the accomplishment of the mission".

Commanders are invariably supported by a *C2 system*, defined as "the facilities, equipment, communications, procedures, and personnel essential to a commander for planning, organizing, directing, and controlling operations of the assigned resources in accomplishing the mission" (likewise adapted from JP1-02, 2016). Facilities means fixed infrastructure, such as buildings, and equipment includes portable items, such as computers, radios, and phones. Personnel refers to other people who assist the commander in gathering information, providing (typically specialist) advice, and implementing or disseminating decisions. The commander and assistants will be collectively termed the *command team*. The team's functions are given by the latter part of the definition. While the original JP1-02 definition reads "planning, directing, and controlling", the list of functions has been expanded to simplify identifying scientific disciplines. The functions may be characterized as follows:

- *Planning*: establishing mission goals, decomposing them into sub-goals (a.k.a. *command concept* or *command intent*), deciding in advance what to do, how to do it, when and where to do it, and with what resources, formulating this as a plan, and testing it (e.g. by simulation or rehearsal). Where time permits, alternative plans or plans with contingent branches may be developed to cope with uncertainty, with the best being selected.
- *Organizing*: obtaining the resources needed to execute the plan, and deciding to whom the tasks and resources should be allocated, bearing in mind the strengths and weaknesses of subordinates.
- *Directing*: communicating command intent, motivating subordinates, allocating them tasks and resources, and coordinating (a.k.a. synchronizing) their actions.
- *Controlling*: monitoring the execution of the plan, detecting deviations, and evaluating these deviations to determine how the plan needs to be modified to achieve the mission.

Ideally, planning and organizing will be done during the Preparation phase of the EM life-cycle, and directing and controlling during Response and Recovery. In practice, however, it may be necessary to re-plan, obtain additional resources, and/or re-allocate tasks on-the-fly during Response and Recovery if the original plan proves unworkable.

Scientific literature

The scientific literature on C2 includes books, journals, and conferences. C2-related books are published by the AFCEA International Press, by the US DoD's Command & Control Research Program (CCRP)[1], and by Ashgate Press in their Human Factors in Defence series. Other relevant books include Van Creveld (1985), Harris & White (1987), Beam (1989), Coakley (1991), and Builder, Bankes & Nordin (1999). The only C2-specific journal was the CCRP's International C2 Journal (IC2J), which published five volumes from 2007 to 2011[2]. There is a wide variety of journals that occasionally publish C2-related papers, e.g. the International Journal of Man-Machine Studies, IEEE Systems, Man & Cybernetics, etc. There are two C2-specific conferences: one is the International Command & Control Research & Technology Symposium (ICCRTS) in the military domain and the other is ISCRAM, in the (civilian) EM domain. As for journals, there is a wide variety of mono-disciplinary conferences that also accept C2-related papers.

Searching this literature reveals very few publications on the science of C2. Harris & White's (1987) book is one, albeit exclusively technically oriented (and dated). AFCEA International Press published three volumes of collected papers on the science of C2 (Johnson & Levis, 1988) (Johnson & Levis, 1989) (Levis & Levis, 1994), and there is one ICCRTS paper (Cropley, Sproles & Cook, 2005).

In their Preface, Harris & White (1987) sum up the state of C2 in the late 1980s as follows:

"Looking to the future of command and control, there are four essential problems:

1. There is no theory or design methodology for command and control of complex systems.
2. There is an information chaos associated with the diverse nature, sources and wealth of data available in large scale systems.
3. There is a technology revolution associated with the enabling technologies of [C2] systems (…).
4. There is an organisational chaos associated with diverse uncoordinated projects, lack of interoperability, lack of software portability, use of different management techniques, etc." (ibid., p.xi)

While Harris & White (1987) noted that there was substantial research being devoted to C2 in Europe and North America, they believed that a fundamental solution could be found by developing a system architecture and implementation strategy. In short, they focused solely on technical aspects.

The CCRP books, journal articles, and conference papers are focused on network-centric operations (NCO) (Alberts, Garstka & Stein, 1999), a.k.a. network-enabled capabilities (NEC) in NATO and Europe. In the beginning, NCO/NEC thinking was technically oriented, finding its inspiration in communications networks

[1] See http://www.dodccrp-test.org/ccrp-books/.

[2] See http://www.dodccrp-test.org/c2-journal/.

(and the Internet in particular). This broadened out to include organizational aspects when researchers showed that the claimed advantages of NCO/NEC often suited decentralized organizations better than the traditional, centralized military hierarchy. The introduction of socio-technical systems ideas opened out C2 research to include cognitive and social psychology. These disciplines were applied to human factors in C2 systems and to regarding command teams (especially in multi-organizational coalitions) as social networks. Eventually, C2 was seen in the CCRP community as linking the physical, informational, cognitive, and social worlds (Alberts, Garstka, Hayes & Signori, 2001).

The older AFCEA three-volume series on the science of C2 focused on coping with uncertainty, complexity, and change. Being collections of articles from AFCEA symposia, with contributions from military officers, government, and industry, as well as researchers, these volumes offered no coherent, overarching theory of C2. Key scientific contributions focused on modelling the C2 process (Levis & Athans, 1988) (Mayk & Rubin, 1988) (Hitchins, 1994), on decision making (Klein, 1988) (Klein, 1994), and on organization theory (Crecine & Salomone, 1989) (Levis & Perdu, 1994).

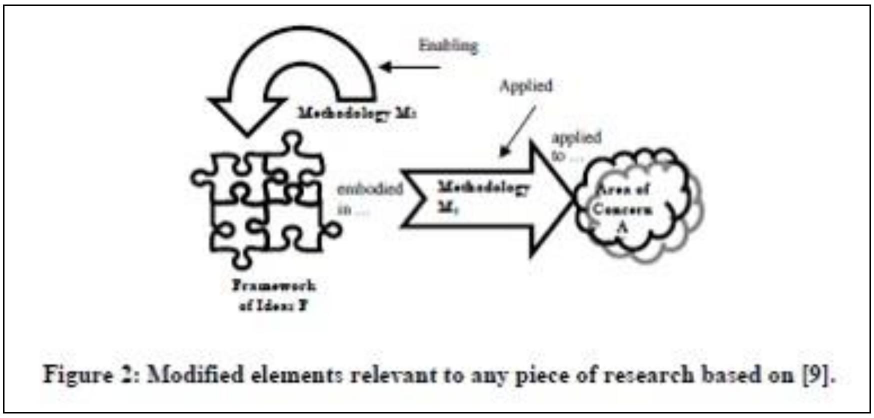

Figure 2. Elements of Cropley et al (2005) schema.

A search of the complete ICCRTS proceedings reveals just one paper proposing an overarching science of C2. Cropley et al (2005) endeavour to provide a rigorously defined schema for the systematic study of C2. Based on Checkland (1985), Cropley et al's schema consists of four elements (see Figure 2): a framework (F) of ideas (a.k.a. body of knowledge) is used in a methodology (M) to investigate some area (A) of concern. The methodology is itself split into two components: M1 is the methodology needed to apply the knowledge in F, and M2 is the process of acquiring knowledge to add to F. Applying Cropley et al's schema to C2, the area of concern is C2, and the knowledge in F is about managing emergencies.

Cropley et al's (2005) schema can be regarded as a meta-theory because it provides three views at the meta level, with scientific disciplines at the lower level. The three views are:

- *Command arrangements.* According to Cropley et al (2005), command arrangements describe the degree of operational authority between headquarters, formation, and units and are concerned with assigning missions and tasks. They cover organizational issues such as the number of echelons in an organization, the span of control, patterns of linkages, and whether relationships are transitory or permanent. In short, command arrangements are the product of planning and organizing, ideally occurring before the operation begins.
- *Command.* Cropley et al (2005) state that command covers the management, leadership, and/or coordination of the activities of a large and complex military force spread over a wide geographical area. Command focuses on the person of the commander. In short, command is the product of directing and controlling, and occurs in real time during an operation.
- *Command support systems.* Cropley et al (2005) state that command support systems include headquarters staffs, communications networks, doctrine, messaging systems, computers, maps, and geographic information systems, software, standardization agreements, procedures, control measures, and databases. They specifically relate command support systems to C2 systems.

In their paper, Cropley et al (2005) developed a generic matrix, with the four elements in their schema as rows and the three views as columns. The results they obtained by filling in the cells are shown in Figure 3.

Table B.1: Generic C2 Research Profile Matrix (RPM)

Elements of Research (Checkland & Holwell, 1998)	Domain: Military Command & Control (C2)		
Area of Concern	Command Arrangements	Command	Command Support Systems
Framework of Ideas (the body of knowledge)	Politics, political science, organisational theory, diplomacy, systems thinking.	Cognitive sciences, decision theory, sociology, anthropology, military strategy and tactics ("The Art of War"), systems thinking, command philosophy.	Engineering science, computer science, doctrine, operating procedures.
Applied Methodologies (M_1) (that support the application of the body of knowledge)	Interpretive: Political science, organisational design, soft systems methodology (SSM).	Interpretive & Functionalist: Enterprise framework practice, cognitive workflow analysis, information systems, command practice, ethnography, historical methods.	Functionalist: Systems engineering, communications science, systems architecting, DoD architecture framework (DODAF) practice, doctrine refinement.
Enabling Methodologies (M_2) (that support the acquisition of the body of knowledge)	Interpretive: Organisational design & analysis, political science.	Interpretive & Functionalist: History, decision theory, ethnography, psychology, sociology, experimentation	Functionalist: 'Hard' science (quantitative, experimental), engineering science, information theory.

Figure 3. Cropley et al's (2005) generic C2 research profile matrix.

The research reported in this paper focuses on systematically expanding on the disciplines they identified in the Framework of Ideas row of the matrix. Methodologies have yet to be studied.

ILLUSTRATIVE SCENARIO

A car crash is an everyday example of a small-scale emergency. It is confined to a small geographic area and involves few people. Nevertheless, it involves coordination between several organizations.

In our scenario, we assume that a car slips on a patch of ice, colliding with a tree at the side of the road, and comes to rest back on the road. The occupants are injured and trapped in the car. Fortunately, there is no fire.

For C2 purposes, the incident begins when a bystander calls the emergency telephone number (e.g. 112 in Europe or 911 in the USA). The emergency control centre answers the call, asking the bystander for details about the location of the incident, the number of vehicles involved, and the occupants' injuries. The control centre despatches a police motorcyclist to direct traffic and onlookers, a fire truck to free the trapped occupants, and an ambulance to take the injured occupants to hospital. The information collected by the control centre is transmitted electronically to the motorcyclist, fire truck, and ambulance, and perhaps supplemented by information available in the vehicle (e.g. from a navigation system).

Following procedures, the leader of the firefighting crew becomes the on-site incident commander. On arrival, he/she checks in with the control centre, and then directs two crew members to collect equipment from the fire truck, while another crew member administers first aid to the trapped occupants. A third crew member stands by with equipment to dowse a fire, should one start. The onsite commander reports events as they happen to the control centre.

When the ambulance arrives, its crew takes over giving first aid, while the fire crew cut the occupants free. The ambulance crew then place the occupants on stretchers, and load them into the ambulance. In the meantime, the control centre has found a suitable hospital to treat the injured occupants, and passed this information to the ambulance crew. The ambulance sets off to the designated hospital.

Once the occupants have been freed from the car, the onsite commander radios the control centre to ask for a tow-truck to remove the car. After removal, the fire crew sweep up any debris, allowing the police motorcyclist to let the traffic flow normally. The onsite commander declares the incident as over, and releases the first responders to return to their stations.

ENTITY-CLASSES AND RELATIONSHIPS

Entity-Classes

The entry-point for identifying entity-classes is the definition of C2. This definition centres on the commander, who fulfils a specific function, namely exercising authority and direction over resources to achieve the mission. The commander is a person, and his/her resources will invariably include other persons, namely the commander's subordinates. Therefore, the first entity-class we identify is **Person**.

Implicitly, the commander and resources are embedded in an organization. One clue is the phrase "properly designated", implying a social institution with rules or laws. A second clue is that resources are assigned, and a third is that the commander has authority over those resources. These clues lead us to identify the **Organization** entity-class.

The verb "exercises" shows that C2 is about performing action. That action is purposeful is indicated by the phrase "accomplishment of the mission". These observations yield the entity-classes **Action** and **Mission**. Although a mission may be decomposed into lower-level tasks, we regard each task as just another instance of the Mission entity-class. Actions and missions are situated, so that a particular action may be successful in one situation but fail in another. Likewise, a mission may be appropriate in one situation but not in another. Hence, we identify the **Situation** entity-class.

We have already observed that the commander's resources include persons. Other resources will be technological in nature, such as vehicles, radios, buildings, and machines. In particular, we are interested in resources that incorporate information and communication technology (ICT). For this reason, we identify the **Technology** entity-class. While this entity-class could be sub-classed, we refrain from doing so for simplicity.

Finally, we identify two intangible entity-classes. First, the persons involved are exchanging information. For example, the commander directs his/her resources, i.e. gives subordinates instructions. Subordinates will also coordinate their actions with other subordinates and report progress in achieving their mission back up to the commander, even though the definition does not allude to such information exchanges. To model an exchange of information, we identify the **Message** entity-class. Second, the actions of the commander (and other persons) will be guided by knowledge, whether gained in the classroom, on exercise, or in real operations. Hence, we identify the **Knowledge** entity-class.

Some additional discussion on persons and organizations is called for. In emergencies, commanders and their subordinates are usually professionals, e.g. police, fire-fighters, medical, and rescue personnel. However, as the scenario shows, there are also other people, e.g. victims (like the occupants of the car), volunteers (like the bystanders who called 112/911 and administered first aid), and the unaffected (like the onlookers). In the EM literature, the other people that professionals must deal with are known as citizens. In the context of communication flows in EM, Manso & Manso (2012) have identified four roles that Persons may play in an emergency: as commanders (typically in a command centre), as first responders (in the field), as citizens (victims), and as citizen (unaffected). To Manso & Manso's scheme we add the citizen (volunteer) role. To demonstrate that these are roles, and not entities in their own right, we note that a particular individual may change role during the course of an emergency. For example, if an unaffected citizen is injured or helps a first responder, then he/she becomes a victim or volunteer, respectively. For the purposes of this paper, we regard role as an attribute of the Person entity-class. Further research (e.g. for more complex scenarios) may show that it is better to regard role as a separate entity-class, with subclasses following Manso & Manso's scheme.

A similar scheme is needed to identify the roles that organizations play in EM. We have not found such a scheme in the literature, but it is possible that one exists, e.g. in UN OCHA.

Relationships

Linking entity-classes by key relationships helps to identify the scientific disciplines. We have already observed that people are central to EM. Therefore, we begin with the Person entity-class.

As shown by our discussion of the different roles that a person can find themselves in, one person may have a social relationship with another. For example, a commander directs his/her subordinates, indicating that there is a superior/subordinate relationship between them. A first responder may help a victim, and a volunteer may obtain resources (funds, crowd-sourced maps, etc.) for a commander. Such relationships are represented in the entity-relationship diagram by a loop joining the Person entity-class to itself.

Another key entity-class is Organization. We observe that commanders and first responders are more or less formally related to an organization, often as employees or as contractors. If volunteers organize themselves into groups – think of crowd-mappers, crowd-funding donors, and the users of websites like ReliefWeb – then they call into existence an organization (real or virtual), and become its members. In short, Persons can be members of Organizations.

Many other entity-classes are also related to Persons. Persons use Technology, whether this is to transport resources, to perform actions, or to transmit messages. Accordingly, the Technology entity-classes also has a transport relationship to Persons and other instances of Technology, a transmit relationship to Messages, and a performs relationship to Actions. Often, Technology items are owned by an Organization, namely the same one as the user belongs to. Messages are sent and received by Persons, and Persons possess Knowledge to guide them in taking Actions.

Persons find themselves in Situations. They make sense of the Situation, assessing its desirability. If a Situation is undesirable, the Person may commit themselves to a goal (a Mission) to change the Situation by means of taking Actions. This implies that the Person must create a plan, i.e. a sequence of actions designed to achieve the goal. The Person may adopt a Mission because it meets his/her own needs, or because it is imposed by another Person (i.e. a commander), or because it is shared with other members of the same Organization.

The relationships together with the entity-classes involved (actor and actee) are summarized in Table 1.

Table 1. Relationships between actor and actee entity-classes.

Actor	**Relationship**	**Actee**
Person	`socially related to`	Person
Person	`member of`	Organization
Person	`uses`	Technology
Technology	`transports`	Person, Technology
Technology	`transmits`	Message
Technology	`performs`	Action
Organization	`owns`	Technology
Person	`sends`	Message
Person	`receives`	Message
Person	`possesses`	Knowledge
Knowledge	`guides`	Action
Person	`assesses`	Situation
Person	`commits to`	Mission
Mission	`specific to`	Situation
Mission	`requires`	Action
Action	`changes`	Situation
Organization	`may impose`	Mission

SCIENTIFIC DISCIPLINES

Science is commonly divided into fields of study, known as disciplines or branches. There are three major groups: the formal sciences that study logic, mathematics, and computer science, the natural sciences that study natural phenomena such as biology, physics, chemistry, and astronomy, and the social sciences that study human behaviour and societies. In addition, the applied sciences cover fields such as engineering, medicine, information systems, and applied mathematics, physics, and chemistry. Disciplines relating to C2 are mostly found in the applied, formal, and social sciences.

C2-related disciplines may be identified from some entity-classes, but most are associated with relationships. The disciplines specific to key entity-classes are as follows:

- **Person**. In addition to their physical characteristics, people differ in the ways that they behave and think. The exercise of C2 emphasizes the abilities to think, to make decisions, and, in commanders, to lead other people. Hence, the disciplines of psychology, and more specifically cognitive science, of decision theory, and of leadership theory are key.
- **Organization**. The key disciplines are organization theory and management theory.
- **Technology**. The key discipline relating to Technology is engineering. In computing and communications Technology, computer science (including information systems) is also important.
- **Message**. The key discipline relating to messages is information theory, which includes communication theory.

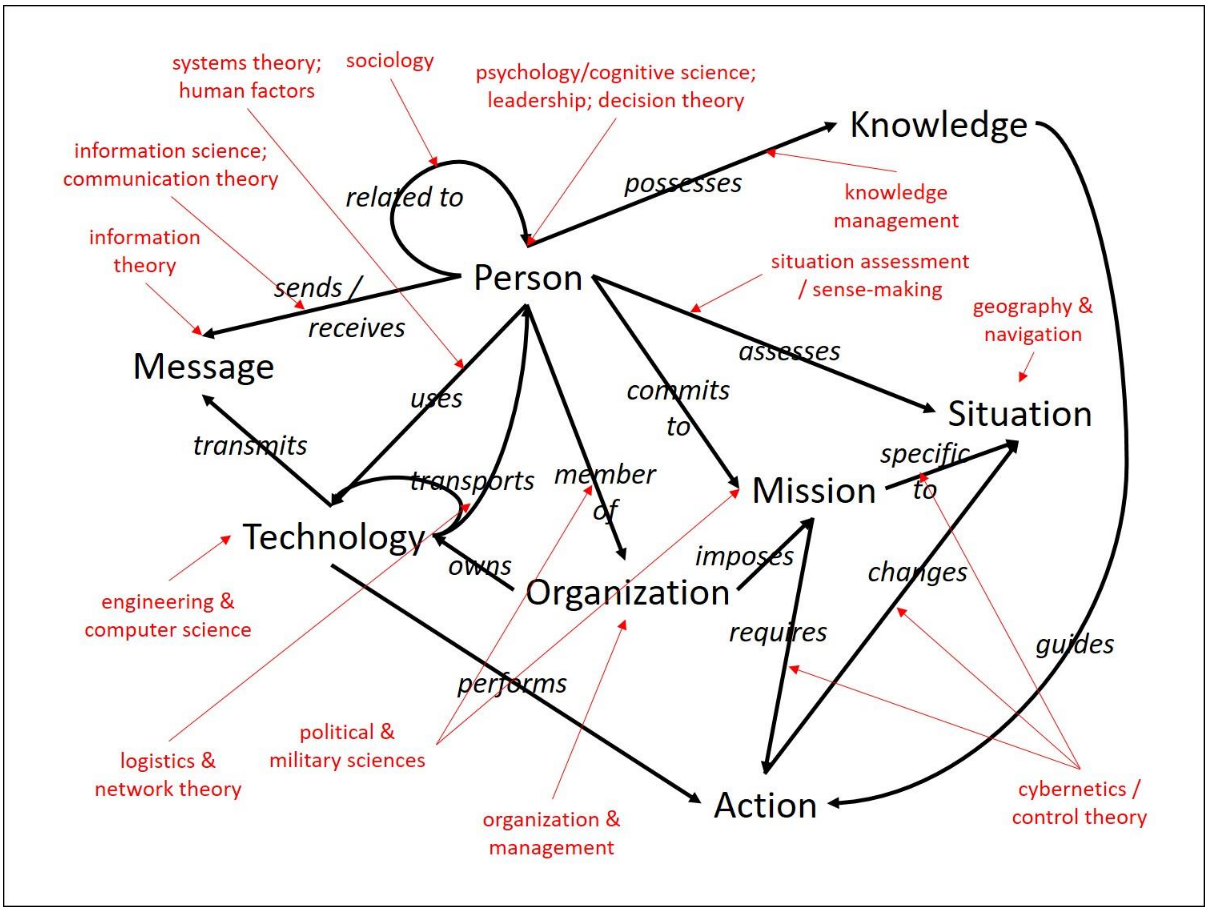

Figure 4. Entity-relationship diagram (in black), with disciplines (in red).

The disciplines relating to the relationships between entity-classes are as follows:

- Sociology is important to understanding the relationships between persons.
- Knowledge management is important to understanding what knowledge people should possess and how they acquire and use that knowledge.
- The psychological sub-disciplines of situation awareness and sense-making are important to understanding how people assess situations.
- Cybernetics and control theory is important to selecting and sequencing actions to change situations to achieve goals, i.e. the set of relationships linking Person, Situation, Mission, and Action.
- Political and military sciences are important to understanding the member relationship linking Person and Organization.
- Network theory and logistics are important to understanding the transportation of people and other

resources and to the transmission of messages.

- Systems theory determines what kinds of technology are most suited to the use by people. Human factors – itself part of cognitive science – determines the usability of technical systems.
- Information science, information theory, and communications theory are important to understanding the exchange of messages between people.

Figure 4 shows the entities and relationships (in black) as a network, with entities as nodes and relationships as links. This network is annotated with the scientific disciplines (in red). The scientific disciplines, together with their Wikipedia definitions, are listed in alphabetical order in Appendix A. Asterisks show disciplines additional to Cropley et al (2005).

COMPARISON WITH C2 DOCTRINE

Doctrine is a codification of beliefs or a body of teaching or instructions in a domain of knowledge. NATO (2016, p.45) defines doctrine as the "fundamental principles by which the military forces guide their actions in support of objectives. It is authoritative but requires judgement in application."

Five documents (two US and three Dutch) detailing military C2 doctrine were reviewed. Common topics in at least four of the documents were:

- Decision making, often represented as a cyclic process with feedback.
- Leadership theory, itself a part of psychology.
- The spectrum from fully centralized to fully decentralized. Mission command refers to the mid-point in this spectrum, where the commander defines the mission and the subordinates determine how this mission is achieved.
- Organization theory in terms of the organizational structure and staff responsibilities.

Table 2 compares the military C2 doctrines with the scientific disciplines identified in the previous section. Doctrinal topics matched with the disciplines of control theory, decision theory, engineering, information theory, knowledge management, leadership, psychology, and organization and management theory.

Table 2. Comparison of military C2 doctrine with disciplines.

MCDP6 (2006)	NDP6 (1995)	NDD (2005)	LD I (2000)	JDP5 (2012)	Discipline
Planning					**Control theory**
OODA	OODA				**Decision theory**
Decision-making	Decision-making	Decision making	Decision making	Decision making	
		Issuing instructions	Issuing instructions	Issuing instructions	
	C2 system		C2 system	C2 system	**Engineering**
DIKW	DIKW				**Information theory**
Comms theory					
Information management					**Knowledge management**
Leadership		Leadership	Leadership	Leadership	**Leadership**
C2 spectrum	C2 spectrum	Mission command	Mission command	Mission command	
Organization theory		Command level, structure & staff	Command level, structure & staff	Command level, structure & staff. C2 principles	**Organization & management theory**
Image theory					**Psychology**
			Ethics & law		**(none)**

Ethics and law fail to emerge from the entity-relationship analysis because they represent constraints on the behaviour of Persons and Organizations. By contrast, entity-relationship analysis is limited to static properties of C2. This indicates that the analysis must be extended to include dynamic properties, such as C2 processes, resilience, and agility.

CONCLUSIONS AND FURTHER WORK

This paper presents work in progress on developing a meta-theory of C2 in emergency management. Most research in C2 focuses just on one or two scientific disciplines. There have been some attempts to approach C2 from a multi-disciplinary viewpoint, including the socio-technical systems approach and the NATO abbreviation DOTMLPFI. One scientific paper (Cropley et al, 2005) has been found that gives a systematic overview of the science of C2, based on three views on C2: command arrangements corresponding to the Preparation phase, command corresponding to the Response and Recovery phases, and command support systems corresponding to the underlying C2 systems.

This paper expands on Cropley et al's (2005) Framework of Ideas. Entity-relationship modelling (Chen, 1976) is used to formalize the meta-theory. First, entity-classes and relationships are identified from the C2 definition, scientific literature, and a small-scale scenario. Then, scientific disciplines are obtained from this model. While the resulting list of disciplines is more extensive than that identified by Cropley et al and in the five military C2 doctrine publications, comparison shows that the analysis must be extended to the dynamics of C2. This would permit developing guidance for practitioners.

Possible further work includes using more complex scenarios, extending the analysis to C2 processes, and comparing the disciplines found with a wider range of C2 doctrine publications and with the proceedings of the ICCRTS (military) and ISCRAM (civilian) conferences, enabling the maturity of C2 research to be assessed.

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Appendix A. Scientific disciplines with their definitions

Discipline	Definition(s)
Cognitive science	Cognitive science is the interdisciplinary scientific study of the mind and its processes, examining the nature, the tasks, and the functions of cognition.
Computer science *	Computer science is the study of the theory, experimentation, and engineering that form the basis for the design and use of computers.
Cybernetics / control theory *	Cybernetics is a transdisciplinary approach for exploring regulatory systems – their structures, constraints, and possibilities. Control theory is an engineering method that deals with the behaviour of dynamical systems and their inputs, and

	how their behaviour is modified by feedback.
Decision theory	Decision theory (or the theory of choice) is the study of the reasoning underlying an agent's choices.
Engineering	Engineering is the application of mathematics and scientific, economic, social, and practical knowledge to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, processes, solutions, and organizations.
Geography & navigation *	Geography is a field of science devoted to the study of the lands, the features, the inhabitants, and the phenomena of the Earth. Navigation is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another.
Information science *	Information science is an interdisciplinary field concerned with the analysis, collection, classification, manipulation, storage, retrieval, movement, dissemination, and protection of information.
Information theory / communication theory *	Information theory is the study of the quantification, storage, and communication of information. Communication theory is a field of information theory and mathematics that studies the technical process of information and the process of human communication.
Knowledge management *	Knowledge management is the process of creating, sharing, using, and managing the knowledge and information of an organization.
Leadership & followership *	Leadership is both a skill and a research area encompassing the ability of an individual or organization to lead or guide other individuals, teams, or entire organizations. Followership refers the capacity of individuals to follow a leader.
Military science	Military science is the study of military processes, institutions, and behaviour, along with the study of warfare, and the theory and application of organized coercive force.
Network theory *	Network theory is the study of graphs (or networks) as a representation of either symmetric relations or, more generally, of asymmetric relations between discrete objects.
Organization & management theory	Organizational behaviour is the study of human behaviour in organizational settings, the interface between human behaviour and organizations, and the organization itself. Management science is the interdisciplinary study of problem solving and decision making in human organizations, with links to economics, business, engineering, and other sciences.
Political science	Political science is a social science discipline that deals with systems of government, and the analysis of political activities, political thoughts, and political behaviour.
Psychology *	Psychology is an academic discipline devoted to the study of behaviour and the mind, embracing all aspects of conscious and unconscious experience as well as thought. Relevant sub-disciplines include: cognitive science, leadership & followership, human factors, human error, and learning.
Sociology	Sociology is the study of social behaviour or society, including its origins, development, networks, and institutions.
Systems theory	Systems theory (or systems science) is the interdisciplinary study of systems in general, with the goal of discovering patterns and elucidating principles that can be discerned from and applied to all types of systems at all levels of nesting in all fields of research.

Ethical, Legal and Social Issues

Agility in crisis management information systems requires an iterative and flexible approach to assessing ethical, legal and social issues

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ABSTRACT

This paper focuses on the assessment of ethical, legal and social issues (ELSI) in relation to agile information systems in the domain of crisis management. The authors analyse the differing needs of a move from a traditional approach to the development of information systems to an agile approach, which offers flexibility, adaptability and responds to the needs of users as the system develops. In turn, the authors argue that this development requires greater flexibility and an iterative approach to assessing ELSI. The authors provide an example from the Horizon 2020 EU-funded project iTRACK (Integrated system for real-time TRACKing and collective intelligence in civilian humanitarian missions) to exemplify this move to an iterative approach in practice, drawing on the process of undertaking an ethical and privacy impact assessment for the purpose of this project.

Keywords

Agile, crisis management, information systems, ethical and privacy impact assessment.

INTRODUCTION

Agility in information systems can be defined as a way to cope with unpredictable change. An agile approach to the development of information systems is a response to a need for the process to be able to consider unexpected changes, vs. traditional models of having a blueprint for a final product and/or system from the start of the project. The development of information systems becomes an agile, flexible and iterative process, rather than having a fixed product and/or system idea that does not change or evolve as the development process occurs. Requirements and solutions evolve through collaborative efforts and agile information system development considers the needs of end users and other stakeholders. Whereas traditional approaches had their requirements defined from the beginning of the project, agile methods focus on quick response to change and continuous development. Agile approaches therefore offer flexibility and adaptability in response to user requirements, which can be essential within the crisis management domain, which by its inherent nature is fast evolving.

Methods and approaches for the development of agile information systems are gaining greater acceptance in practice. Agility is defined as "“the continual readiness of an ISD method to rapidly or inherently create change, proactively or reactively embrace change, and learn from change while contributing to perceived customer value (economy, quality, and simplicity), through its collective components and relationships with its environment" (Conboy 2009: 340). Change is therefore vital and one of the fundamental differences in comparison to traditional models of the development of information systems. The development process is thus split into smaller increments with constant feedback from the customer, end user and/or stakeholders (Cao et al. 2009).

In this paper, the authors use the example of the European Union (EU) Horizon 2020 funded project, iTRACK[1] (Integrated system for real-time TRACKing and collective intelligence in civilian humanitarian missions), to discuss the ethical, legal and social issues involved in a specific example of an agile information system for humanitarian response. iTRACK is a three-year project focused on improving the protection of humanitarian workers and effectiveness of humanitarian missions with integrated intelligent socio-technical tracking solutions to support threat detection, navigation, logistics, and coordination in humanitarian disasters.

The latest report by Humanitarian Outcomes (2015) revealed that in 2015, 287 aid workers were victims of major attacks, 109 were killed, 110 were wounded and 68 were kidnapped (an additional 11 aid workers that were kidnapped were killed). Such numbers emphasise the need for improved information systems for enhancing the protection of humanitarians operating in conflict zones. As such, the collective intelligence and intelligent systems developed by iTRACK aims to play an important role in boosting protection, safety and security of humanitarians, and efficiency of response. It will do so by providing the means for responders on the ground to acquire valuable information in real-time, to help them self-assess the situation, make informed decisions, and communicate and organise their response. iTRACK recognises the fact that technological innovation can only be successful if it addresses decision-makers' needs, and will therefore also work on policies to reflect work practices and decision-making procedures of humanitarian responders. iTRACK combines technology and process innovation that supports enhanced self-organisation of civilian humanitarian responders. The project results, along with the developed algorithm will be implemented, deployed and tested in simulations with humanitarian practitioners. The results will also feed into pilot applications with the World Food Programme (WFP) and iMMAP. The iTRACK system utilises an agile development process – iterative and reflexive in terms of design and in response to the needs of humanitarian workers and end users.

However, with increased technological capabilities and agility come new, as well as familiar, ethical, legal and social issues (ELSI) to be taken into account. In order to consider these ELSI, one approach is to conduct an ethical and privacy impact assessment (E/PIA). This paper provides an overview of the authors undertaking an E/PIA in relation to one technological solution for humanitarian response developed for the iTRACK project. In this paper, the authors show that undertaking an assessment of the ethical, legal and social issues in relation to agile information systems in the crisis and disaster response domain requires an agile (flexible and reflexive) approach to assessing the aforementioned issues. Projects such as iTRACK therefore not only respond to needs in the humanitarian sphere, but also have the potential to push forward methodological approaches to assessing ethical, legal and social issues in this area, as well as the wider domain of the governance of new and emerging technologies more generally. The example of iTRACK used in this discussion paper is based on work in progress. The position taken by the authors is one that sees the need for future practice in the area of assessing ELSI issues, in relation to technologies and information systems development for humanitarian response and crisis management, as requiring an on-going and continuing assessment of these issues and an embedded approach to E/PIAs. This embedded approach requires researchers conducting the E/PIA to be involved at every stage of the project and/or design of the system. The authors return to this issue in section two of this paper.

The first section of this paper provides a more in-depth overview of agility in relation to crisis management. It highlights that crises are fast moving and unpredictable and therefore require, not only agile information systems, but also agile working environments. Furthermore, this section suggests that the end user, and their needs, must be taken into account in relation to agile information systems. This section moves on to discuss the overall aims of the iTRACK project, as well as providing an overview of the system architecture. The iTRACK system is shown to comprise hardware and software elements for use in a range of humanitarian responses and countries. These elements will combine to form an information system respondent to the needs of end users as the system develops.

The second section of this paper focuses on assessing the Ethical, Legal and Social Issues (ELSI) in relation to

[1] The project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 700510

agile information systems. This part of the paper details the process undertaken by the authors in relation to an ethical and privacy impact assessment (E/PIA) for the iTRACK project. Information systems have the potential to improve humanitarian action, as well as ensuring a higher level of safety for humanitarian workers, however there are also ethical, legal and social issues to take into consideration when designing these systems. In this section, the authors describe the process of assessing a range of issues for the ITRACK project, and how the original approach has been altered in the context of the project, in order to align the E/PIA process with the process of developing an agile information system. This section concludes with the authors' deduction that agility in information systems requires an embedded E/PIA process and an iterative method for assessing the ELSI issues that arise.

CRISIS MANAGEMENT AND THE ITRACK SYSTEM

Agility in crisis management

Conflict zones and environmental hazard areas are highly volatile operational environments that are characterised by high complexity, difficulties in access, and extensive needs of support in staging areas outside of the operational theatre. Further, humanitarian crises, whether resulting from war or from natural disasters, can be unpredictable in how they unfold, multiply, who they affect and what risks they result in. For example, in Syria, the level of violence and disregard for humanitarian action has been unpredictable. Likewise, the crisis in Haiti was described as a humanitarian crisis of unpredictable proportions, especially with the number of victims claimed by the cholera outbreak.[2] It is also apparent that there is a great deal of potential for contexts to change and thus the feasibility of using specific technologies alters. The security situation is highly dynamic and places strong requirements on situational awareness, constant negotiations for access, and dynamic routing and rerouting capabilities.

Further, every crisis is unique in terms of its socio-economic and environmental context. This quality, together with the trait of being unpredictable means that stakeholders struggle to interpret or respond to crises, as they have no relevant and up-to-date frame of reference. New situations require a fast consideration of how they should be conceptually constructed and how to practically respond.

It is therefore the very nature of crises - unpredictable and fast moving - which means that they require agility at an organisational level. However, as argued by Harrald (2006) this agility cannot come at the expense of discipline. For Harrald (2006: 257), those involved in developing systems for crisis response must pay attention to what he refers to as "discipline (structure, doctrine, and process) and agility (creativity, improvisation, and adaptability)". Consequently, agile information systems alone cannot support crisis management efforts; rather there is a need for such systems to be used in an agile working environment. Similarly, for Mendonca et al. (2007: 49), who argue that "the technological systems we design and build must enhance – not impede – organizational agility", information systems need to be reactive and effective. These information systems need to understand the environment that the user is working in. Information systems also need to be interoperable systems, supplying the user with a range of choices of functionality in real-time that they can select to enhance their own operations (Mendonca, et al., 2007). Thus, information systems and the end user must be considered together to ensure reliable and efficient systems.

The iTRACK System

As stated in the introduction, this paper will focus on one particular project – iTRACK – in order to exemplify the need for an agile approach to assessing the ethical, legal and social issues that arise when utilising agile information systems in the humanitarian context. The objective of the iTRACK project is to create an open-source real-time tracking and threat detection system, providing intelligent decision support to civilian humanitarian missions for the purpose of better protection, and more efficient and effective operations. This objective will be achieved by developing technologies that enable information-driven self-organisation and coordination, as well as rapid adaptation to dynamically changing situations and threats. In order to achieve this overall objective, iTRACK has developed six sub-objectives:

I. Extract and analyse organisational and technical system requirements. Design policies for tracking information management (IM), logistics and risk management in humanitarian missions.
II. Automatically monitor locations. Identify, process and assess threats and humanitarian needs in distributed response settings by using heterogeneous data sources.
III. Develop real-time decision support for risk mitigation and protection; navigation, routing and

[2] EU business, *Haiti facing unpredictable crisis, EU double aid, [online]* http://www.eubusiness.com/news-eu/haiti-cholera-aid.7lh/, accessed 13.1.17

scheduling; coordination based on threats and needs identified continuously updated with live information.

IV. Provide secure and reliable communication in the iTRACK platform and develop secure IM policies.

V. Deploy and validate the iTRACK platform and policies in simulations and real-world settings.

VI. Disseminate project results and build up a network of early adopters. Disseminate training cases for IM in conflicts.

The threats of conflict and disaster place increasing pressure on the humanitarian community to protect those individuals at risk. It is envisaged that the humanitarian community will benefit from the research, namely: agencies, personnel deployed in conflict areas, policy and logistics developers. Moreover, a better, effective and timely humanitarian relief operation has the capacity to save thousand of lives. The recipient countries therefore benefit indirectly from the research as well.

Consortium members of the iTRACK project have described the iTRACK system as a ‘system of systems’. As seen in Figure 1 (below), it combines software and hardware development to advance towards an information system for use in a range of humanitarian responses and countries. Furthermore, technology requirements for various locations may differ, highlighting the importance of the modularity and flexibility, which will be reflected in the iTRACK system.

As it stands, the main foreseen technological elements of iTRACK include: on-board cameras, sensors, location devices and threat detection; a mobile app; smart watches and wearable tracking devices; a web app and iTRACK dashboard; and the development of an iTRACK platform incorporating a storage system, social media collection, routing and logistics, and decision support and alerts.

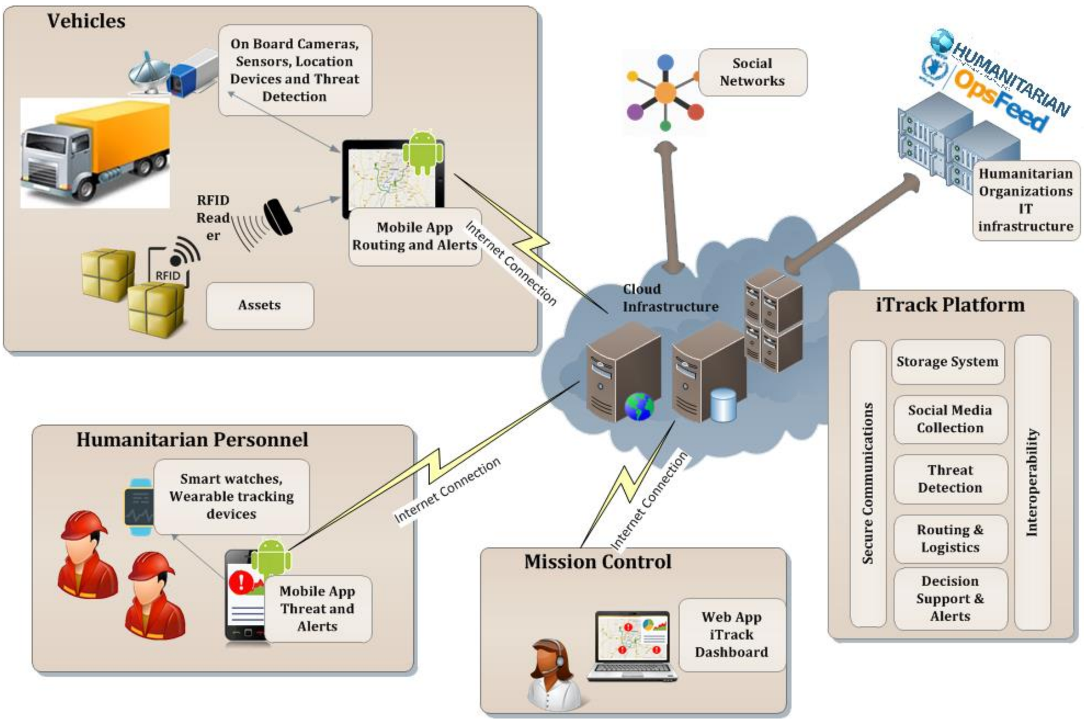

Figure 1: iTRACK System Architecture

As one of the core outcomes of the project is a novel system, it is important to undergo a review of what already exists, what does and does not work and what is needed. To that end, at the outset the project, partners engaged in an analysis of workflows and processes in the areas of humanitarian information management (IM), logistics, and coordination and technology. The results of this analysis, which included empirical research in the form of interviews with humanitarian workers in the field, and those responsible for policy, is a taxonomy of current approaches and solutions as well as existing gaps. iTRACK also focuses on unique relevant operational situations and analyses Syria vs. Iraq as conflict zones, and Jordan as their common support and staging area.

Following on from investigating workflow processes, the technology partners are currently engaging in technology deployment. In the first phase, they are developing the architecture, design and implementing the end-to-end iTRACK platform. In the next phase, they will develop, implement and test the constituting collective intelligence components that provide input to the first phase for the integration, verification, testing and consolidation of the final iTRACK system. This will be followed by use of simulation and evaluations to test the system.

ETHICAL, LEGAL AND SOCIAL ISSUES

Assessing Ethical, Legal and Social Issues in relation to Agile Information Systems

Novel, digital and web-based information and communication technologies (ICT) have the potential to improve humanitarian action. As argued by Meier (2015), big data analysis can, for example, rapidly provide decision makers with a realistic overview of a conflict situation. Such technology is an example of what Vinck (2013) describes as humanitarian technology; in other words, technology that improves the quality of prevention, mitigation, preparedness, response, recovery and rebuilding efforts. However, there are also potential drawbacks; humanitarian technology solutions may "compromise the core principles of humanitarian action and obscure issues of accountability of humanitarian actors towards beneficiaries" (Sandvik et al. 2013: 3). In addition, some of the victims of humanitarian disasters or humanitarian workers may be in a vulnerable position, whereby they are pressured in emergency situations, making them more susceptible to accepting conditions and consenting to situations and/or technologies they may otherwise not have done.

As mentioned in the introduction to this paper, one approach for assessing the ethical, legal and social issues that derive in designing complex information systems is to undertake an ethical and privacy impact assessment (E/PIA). An E/PIA is a systematic process for identifying and addressing ethical and privacy issues in an information system, whilst also considering the future consequences and impacts of proposed actions in relation to ethics and privacy. It can be described as an early warning system that can help expose risks regarding the system under development (Wright, 2012: 55). The term and approach has arisen from work undertaken in the area of privacy impact assessments (PIA). The term PIA emerged during the 1990s. It has been suggested that precursors to the concept of PIA were Technology Assessment (TA), utilised by the Office of Technology Assessment (OTA) in the US, and the concept of an Environmental Impact Statement (EIS) (Clarke 2009). A PIA is a tool for identifying and managing risks to privacy and/or data protection. It is a process that focuses on identifying the impacts on privacy of any new project, technology, service or programme (Wadhwa and Wright 2014: 14). There are, however, a variety of approaches to conducting PIAs worldwide and a number of definitions attributed to the term. Under UK guidance (ICO 2009), a PIA is defined as "A process, which helps assess privacy risks to individuals in the collection, use and disclosure of information. PIAs help identify privacy risks, foresee problems and bring forward solutions". The Office of the Privacy Commissioner of New Zealand defines a PIA as "a systematic process for evaluating a proposal in terms of its impact upon privacy". Following on from work undertaken in the area of PIAs, the term ethical and privacy impact assessment was coined by Trilateral Research and Consulting during the EU FP7 project, PRESCIENT (Privacy and Emerging Sciences and Technologies). This approach draws on additional legislation, regulation and frameworks, such as the: United Nations Convention on Human Rights 1948 (UNCHR) and the European Convention on Human Rights 1952 (ECHR).

iTRACK provides an interesting example for a paper focused on agile information systems. The developers of the system have to adapt to the needs and requirements of end users, but also to the requirements and contexts of the countries in which the system will operate once the project is underway and the system is being piloted. The iTRACK system is being piloted in conflict areas in the Middle East. The project results will be implemented, deployed and tested in simulations with humanitarian practitioners during pilot applications with the World Food Programme and iMMAP in on-going conflict disasters in the Middle East (Syria, Yemen and Iraq). Many countries in this region have limited or no data protection regulation, or Data Protection Authorities (DPAs). Furthermore, human rights legislation containing over-arching ethical principles, such as the European Convention on Human Rights 1952 (ECHR), which one might consider as a first port of call when developing a framework for undertaking an impact assessment in EU countries, are generally lacking in these countries. Although there are examples of international frameworks, such as the Universal Declaration on Human Rights 1948 (UDHR), this is not always adhered to across Islamic States and conflict areas in the Middle East, and has been argued to be in conflict with Sharia Law (the Declaration is not legally binding). Studies suggest that Muslim state leaders have taken issue with several areas contained in the UDHR, such as, for example, equal rights (DeLaet, 2006), and religious freedom and religious minority (Donnelly, 2007).

The iTRACK project is an EU-funded project and takes a European-centric view of ethics and privacy. The framework for the iTRACK E/PIA has therefore been based on what the authors consider to be the 'gold standard' in terms of privacy and ethics. The principles embedded in the framework for the E/PIA for iTRACK consist of those taken from: the Universal Declaration on Human Rights, the European Convention on Human Rights 1952, the General Data Protection Regulation, and ISO 29100:2011 (Privacy Framework). These principles consist of:

Dignity	Fairness	Justice (right of inspection and redress)	Purpose legitimacy and specification
Autonomy	Security	Solidarity, non-discrimination and benefit sharing	Collection limitation
Informed consent	Responsibility	Reducing inequality	Data minimisation (necessity)
Trust	Avoidance of harm	Consent and choice	Use, retention and disclosure limitation
Accuracy and quality	Openness, transparency and notice	Individual participation and access	Access and correction
Accountability	Information security	Privacy compliance	

Figure 2: Ethical and legal principles

The method used for the iTRACK E/PIA has, and will continue to be developed alongside the project. The original approach outlined in the proposal consisted of: planning a timetable and approach for the E/PIA; a two-day workshop, including 10 interviews conducted at the time of the workshop; and the development of an E/PIA report. The approach specified in the proposal has been amended to include a set of five interviews with technical partners, conducted prior to the E/PIA workshop, to map the preliminary information flows for the iTRACK system. Five further interviews will be conducted throughout the remainder of the project with both technical partners and end users, to feed into the final ELSI report. The workshop was reduced to a one-day workshop due to the research work being undertaken beforehand.

The authors decided that due to the complexities of the ITRACK system it would be beneficial for the partners to be provided with a description of the information flows for each element of the system at the beginning of the workshop. The aim of the interviews, conducted by the authors of this paper with the technical partners, was to gain an understanding of how data would be processed by each element of the system. In turn, the authors provided graphical representations of these information flows during an E/PIA workshop as a starting point for discussion.

The iTRACK E/PIA workshop was held in November 2016 with the partners in the project and an external expert in ELSI within crisis management. The aim of the workshop was to present the information flows to technical partners, end users and other members of the consortium, and to identify and assess the risks that may arise when developing and implementing the iTRACK system. The workshop also incorporated an element of developing a set of solutions to the risks identified. Originally, the authors envisaged undertaking a threat and vulnerability mapping exercise, however due to carrying out an internal practice run of the workshop with technical experts from the partner leading the E/PIA process, Trilateral Research Ltd., it was decided that this mapping exercise would not achieve results in practice, and would therefore be undertaken after the E/PIA workshop. The approach to undertaking this E/PIA was therefore amended due to the nature of the project and the complexity of the iTRACK system.

During the workshop participants were provided with an overview of the information flows and the embedded ethical and privacy principles, and were asked to consider any possible negative consequences that could emanate from using the iTRACK system with regard to ethics and privacy. To kick-start the discussion the workshop facilitator provided participants with fictional scenarios that described humanitarian workers using the iTRACK system. Participants could read these scenarios and try to identify risks related to ethical and privacy principles.[3] They were then asked to think outside of the scenarios and come up with other risks. The discussions were split into groups of around four people, and each group was responsible for one element of the iTRACK system, e.g., the on board camera. After the breakout session the groups presented their findings to all participants.

A number of risks were identified during the workshop. By way of an example, a key concern was the possibility of the system being hacked and the seizure of data. Furthermore, participants identified a lack of connectivity, network and power as potential weaknesses, which could lead to a failure of the iTRACK system and in turn the possible compromising of a humanitarian mission. It was also acknowledged that there might be numerous risks with regard to the multi-faceted surveillance character of iTRACK, in particular if the system captures data from third parties who have not consented to their data being collected, or if it captures data on humanitarian workers who are at the time not engaging in humanitarian work.

Subsequently, breakout discussion groups brainstormed the likelihood and severity of the risks, and discussed possible solutions to mitigate negative impacts to ethical and privacy principles. The individual breakout group discussions were recorded (with consent) and notes were taken during the 'global' group discussions.

Developing the E/PIA approach

The authors have been involved in leading two components for this project (the E/PIA and Research Ethics elements). However, since the project began, they have also joined the consortium calls, originally envisaged only for technical partners, in the remaining parts of the project. Reflecting on this development and what this means for the E/PIA process conceptually, the authors have begun to describe this as 'an embedded approach to E/PIAs'. This means that the E/PIA process has become flexible and embedded at every stage of the design process. Although traditionally, a privacy impact assessment (PIA) process has always run throughout the entire lifecycle of the project, it has also only seen active engagement with stakeholders at given moments throughout the project (e.g. in the form of a questionnaire, interviews, a workshop, or another form of consultation). This generally takes place as a one-off consultation with the results included in a PIA report (see for example, De Hert et al. 2013).

The example of the iTRACK project has shown that the assessment of ELSI issues in relation to information systems is of greater benefit through an approach consisting of continuous advice on and engagement with these issues at every stage of the project and throughout the entire design process of the system. The authors have joined all meetings and discussions on the technical elements of the project, providing a continuous assessment of, and advice on the ELSI issues associated with the system design, thereby embedding a rigorous privacy by design approach into the project (for more on the concept of privacy by design, see for example, Cavoukian, 2012; Kroener & Wright, 2014). This has therefore concurrently further developed the authors' approach to conducting E/PIAs from a methodological standpoint.

The authors have learnt that agility in information systems requires this form of embedded E/PIA process and an iterative method for assessing the ELSI issues that arise. As this was a new addition to the iTRACK project and is still a Work in Progress, it will be further developed as the authors further define and develop their E/PIA approach in future projects.

CONCLUSION

This paper has shown that the fast-changing nature of crises requires continuously evolving technological solutions, able to adapt to the needs of given situations. Agile information systems allow technological solutions

[3] Examples of the scenarios provided:
1. Following an attack on a humanitarian organisation in a conflict area, the organisation counts that 34 of their staff members were killed, and 54 have been injured. The media continue to report that in this conflict the lives of aid workers are ever more threatened. There is a shortage of experienced staff to deliver the aid and the organisation sends out some of its newest recruits. They have not used iTRACK before but are given the opportunity to do so now. Time is of the essence; as well as learning about iTRACK they need to digest a range of other information. The staff are local, from ages 24 - 65 and do not speak English.
2. Humanitarian workers are in an area badly affected by a civil war. With the aid organisation increasingly working in riskier environments their mental health is suffering. Wishing to discuss their experiences with persons in similar situations they begin to communicate via the iTRACK communication system.

to be constantly adapted to the needs of end users and those operating in the area of humanitarian work and crisis management. This shift from a traditional model of information systems development, involving a fixed product/system idea from the outset, to one of agile development, involving a flexible approach that adapts to the needs of the environment, end users, and so on, allows developers to respond to evolving needs and requirements. In turn, this has implications for the assessment of ELSI in relation to technological solutions.

The example of the iTRACK project, provided in this paper, illustrates how one approach to assessing ELSI (in this instance, an E/PIA) has been adapted due to the nature of the development of the information system. The method for assessing ethical, legal and social issues has changed from the proposal stage to the implementation of the project, and will continue to evolve throughout the project's lifecycle and beyond. This development has been termed by the authors as an embedded approach to ethical and privacy impact assessment. The embedded approach entails the ELSI assessment process to be involved at every stage of the project and the system design and development, rather than providing a single snapshot of a project at a certain point in its lifecycle.

The authors have therefore amended the overall approach and method to conducting E/PIAs due to their experience in the iTRACK project to date. The authors have learnt that agile information systems development benefit from the continuous involvement of the person(s) responsible for the assessment of ELSI in the design and development of the technology and/or system. The authors have therefore taken the preliminary lessons learnt from this project to start to develop a more flexible and iterative approach to undertaking E/PIAs.

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Machine Learning and Social Media in Crisis Management: Agility vs Ethics

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ABSTRACT

One of the most used sources of information for fast and flexible crisis information is social media or crowdsourced data, as the information is rapidly disseminated, can reach a large amount of target audience and covers a wide variety of topics. However, the agility that these new methodologies enable comes at a price: ethics and privacy. This paper presents an analysis of the ethical risks and implications of using automated system that learn from social media data to provide intelligence in crisis management. The paper presents a short overview on the use of social media data in crisis management to then highlight ethical implication of machine learning and social media data using an example scenario. In conclusion general mitigation strategies and specific implementation guidelines for the scenario under analysis are presented.

Keywords

Machine Learning, Social Media, Intelligent systems, Ethics, Privacy, Mitigation Strategies.

INTRODUCTION

In recent years the amount of emergencies and disasters of various types and duration has been constantly increasing, (see the infographic published by The United Nations Office for Disaster Risk Reduction in Figure 1) and this trends is only going to progress. Designing new services for resilience is now a fundamental requirement: new agile methodologies for emergency management need to be implemented, that are faster and more flexible in identifying challenges, and sourcing and implementing new solutions. Answering to this need, several new methodologies such as crowdsourcing, citizen sensing and sensor technologies have been trialled in recent years (Culotta, 2010; Abel et al, 2012; Meier, 2015; Mazumdar, 2016), to ensure information about a disaster is rapidly acquired and shared, thus allowing faster and flexible reaction to the variety of emergencies.

The most used sources of information for fast and agile crisis information are probably social media or crowdsourced data, as information is rapidly disseminated, can reach a large amount of target audience and covers a wide variety of topics. Information on social media, however, is often i) duplicated, incomplete, imprecise, or incorrect (in some cases, deliberately so); ii) written in informal style (i.e., short, unedited and conversational), thus much less grammatically bounded and containing extensive use of shorthand, symbols (e.g., emoticons), misspellings, etc.; iii) generally concerning the short-term zeitgeist; and iv) covering every conceivable domain. Given the scale of social media and the characteristics of the information, automated methods to monitor and capture the information in social streams are often required. To this extent many new tools have been created to exploit social media and crowdsourcing during emergency, many of them adopting automatic or semi-automatic Machine Learning (ML) algorithms to process information. However, the combination of social data and machine learning algorithms to understand and filter the data has also high ethical implications, as it can introduce several types of bias (i.e. data collection bias, training set bias) during the creation of the models, thus potentially causing misapplication of models and flawed interpretation of results.

Whilst previous papers have analysed the ethics implications of using social media data, in this paper we focus on the implications of using machine learning-based tools (or other automated systems) that learn from social media or crowdsourced data to provide intelligence. We will first of all present a brief state of the art of social media analysis systems for emergencies and of the ethics risks of using social media data for emergencies. We will then explain how the introduction of ML algorithms to analyse the data can introduce new risks and we will discuss the mitigation strategies that can be put in place to ensure a respectful, ethical and effective usage of this channel.

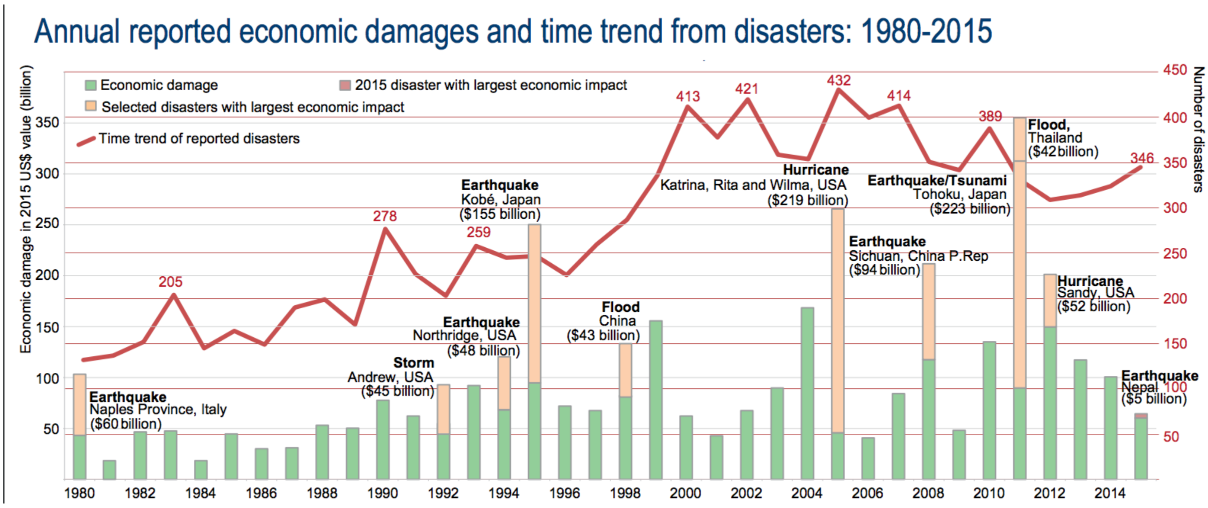

Figure 1 - The United Nations Office for Disaster Risk Reduction disaster trend from 1980 to 2015 (source: http://www.unisdr.org/files/47804_2015disastertrendsinfographic.pdf)

SOCIAL DATA FOR EMERGENCIES – STATE OF THE ART

The use of social media data and crowdsourcing for emergencies has emerged a few years ago, when social media started becoming a major channel to disseminate and share information. Given the vast amount of information on social media and on crowdsourcing applications, finding relevant information in an effective manner has proved problematic: too much information can cause information overload and inability to separate relevant information from noise. To this extent, researchers have worked to create algorithms that analyse the information using NLP (Natural Language Processing) or ML technologies and provide either visual analytics solution to prioritise information, or algorithms for threat detection etc.

Existing systems for the analysis of social media or crowdsourced data vary accordingly to the type of analysis that is performed (e.g. offline or online) and to the intended outcome (e.g. visualization of data or recommendations) but they share the same conceptual idea of using Machine Learning and Information Extraction to extract information from social media streams and use that information to learn patterns and trends and to improve the algorithms.

Various studies have been performed on the possibility of social media data to be a predictor for public health, with research into Twitter Analysis to recognize early warnings for Swine Flu pandemic (Quincey and Kostkova, 2010), Dengue outbreaks (Gomide et al., 2010) and influenza (Culotta, 2010; Lampos, 2010). Another domain where social media data has been extensively researched is natural disasters, for example earthquakes: Sakaki et al in 2010 analysed Twitter data to propose a new algorithm for earthquake detection [Sakaki, 2010]; Caragea et al in 2011 proposed a system that uses Machine Learning (ML) for categorizing Tweets for the Haiti earthquake (Caragea et al, 2011).

Real-time analysis of social media data is often provided by tools that make use of visual analytics to visualize information and trends for users. Twitcident (Abel et al, 2012) uses ML to analyse Twitter Streams in real-time, filtering the Tweets accordingly to emergency categories and providing a set of visualization widgets to see the data. TRIDS is a system for monitoring social media that enables situation awareness in localised events, using Information Extraction techniques to analyse the data in real-time and visualize them using multiple faceted widgets (Ireson et al, 2015). SensePlace2 (MacEachren, 2011) is a geovisual system that using NLP techniques to extract location and time from Tweets and map them accordingly. SocialSensor is a EU project that focuses on real-time analysis of multimedia data streams, developing tools to support journalists and citizens (Papadopoulos et al, 2014), with a focus on emergencies (Papadopoulos et al, 2013).

Whilst social media streams provide large volume of data, the data available may be inconsistent, incoherent and not trustworthy. For this reason research effort in crisis management has focused on crowdsourcing, that is the process of enabling “capable crowds to participate in various tasks, from simply ‘validating’ a piece of information or photograph to complicated editing and management” (Gao et al, 2011). Crowdsourcing platforms have been used in many emergencies to collect information about damages (Yang et al., 2014) or have been used on a daily base to prevent emergencies by collecting sensor information about natural resources and alerting contributors when values are out of the normal range (Mazumdar et al, 2016). A different approach that combines crowdsourcing and social media data analysis has been proposed by Meier (2015), using volunteers' efforts to review automatically categorised social media data.

Whilst these approaches have been proven effective in real-life scenario, there is no doubt that aggregating, fusing, analysing and visualising information can exacerbates the privacy and ethics issues that are already present when dealing with "simple" social media or crowdsourced data (Watson et al, 2013).

ETHICAL RISKS OF SOCIAL MEDIA ANALYSIS – STATE OF THE ART

Unintended consequences of Social media usage in emergencies situations have been analysed in various papers, with examples that show how social media has created an 'unintended "do-it-yourself" society' (Rizza et al, 2012) where social media are used as means of surveillance, without concern for the privacy rights of individuals that may be involved in an emergency. The famous case of identification of a wrong person as suspect for the Boston bombing and the consequences this has been investigated by Tapia et al (2014).
Other research in the area has identified the issues given by the fact that social media users may share information about other people without preserving their privacy: for example Watsons et al (2014) discuss issues raised by people sharing images of victims of the 2005 London Bombing. The rapidity of sharing information on social media means that, if a photo is removed as too sensitive or infringes someone's privacy, it may already be replicated on other channels.

MACHINE LEARNING AND SOCIAL MEDIA FOR EMEWRGENCY MANAGEMENT

Machine Learning is a disciplines that studies, designs and develops algorithms that learn from experience. An example of ML for Emergency Management is the use of facial recognition embedded in CCTV cameras: facial recognition is often used as allows to quickly process millions of faces and recognise similar faces across multiple images but has also been proven as potentially racially and sex-biased (Klare et al, 2012; O'Toole et al, 2011). To better understand the potential ethics issues of applying ML techniques to Social Media it is important to understand how ML Algorithms work. The following image, taken from a Google Research presentation on ML, shows a basic diagram (Figure 2).

A Machine Learning algorithm works by having a set of example to learn from that are inputted into a model. The model is created by selecting a set of variables or factors that are used to make a judgment (prediction or identification) when a new data is presented to the model. A Machine Learning algorithm has also a learner component, that looks at differences between the judgment of the model and the actual outcome or truth to adjust the parameters and in turn the model.

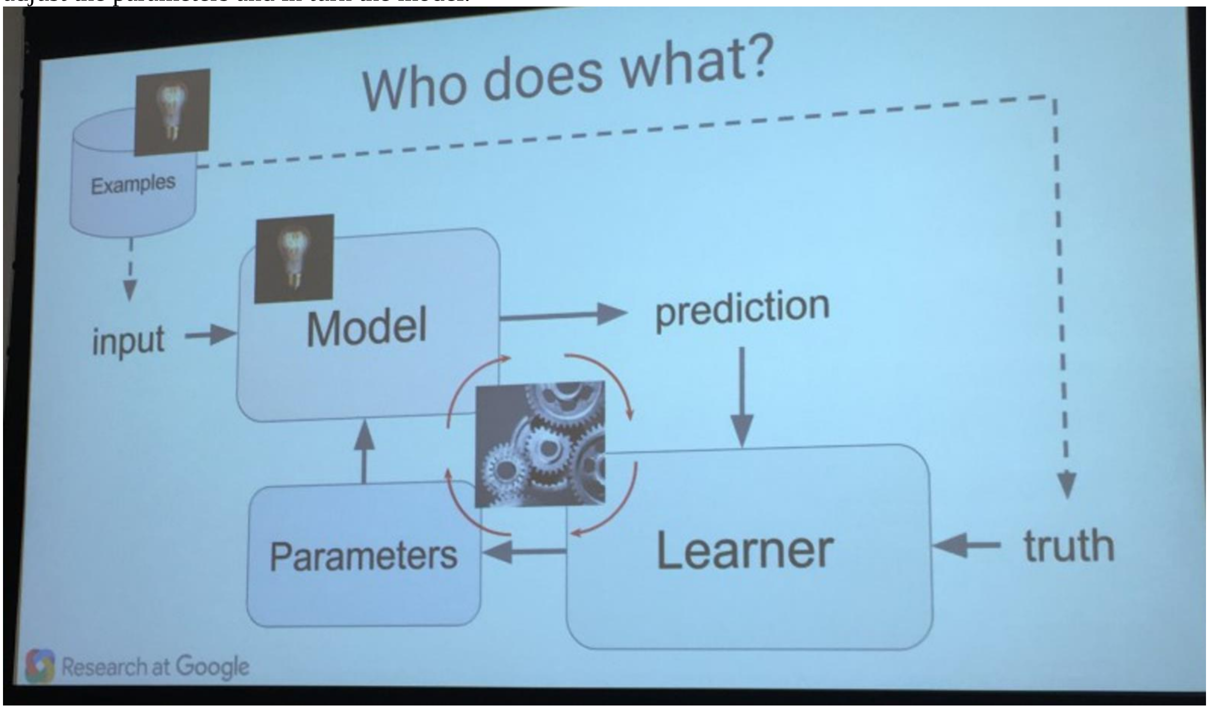

Figure 2 – Google Research Diagram of Machine Learning (source: https://martechtoday.com/machine-learning-day-at-google-150275)

Learning may occur in different manners, for example be supervised, unsupervised, semi-supervised etc. Given the nature of the algorithm process, there is a high risk that a machine learning system can reproduce patterns of discrimination and even exacerbate them (Barocas et al, 2016). Very often machine learning algorithms are "black-boxes" that output results, giving no visibility to the users to how the outcome was reached. Expert users may get visibility of an algorithm working process when analyzing the outcome, but again the visibility is depending on the type of algorithm used: for example, complex neural network algorithms have much less transparency than algorithms based on decision trees or Bayesian networks (Bostrom et al., 2014).

Bias can be introduced in a machine learning systems at different stages on the design and development process. A study by Tiell et al (2016) identified three stages of ethics bias risks when designing and developing a machine learning algorithm:

- ➔ System Design
  - Human Cognitive bias: this is a bias in cognitive processes (identifying, reasoning, abstracting evaluating, etc.), due to the personal preferences and beliefs of an individual (in this case, the system designer).
  - Algorithm selection: this bias occurs as the system designer will make a choice between different algorithms to analyse the data, therefore inheriting bias and risks associated with the algorithm chosen.
  - Data collection bias: this occurs when the data chosen is biased, for example because of non-random selection.
  - Missing or misquantified data: this occurs when data is missing, due to the way data is captured and or/manipulated/processed (e.g. labelled).
- ➔ Modeling and training:
  - Reinforcement bias: this occurs when selective thinking is applied, thus selecting and choosing only the data that confirms the researcher beliefs and ignoring the contradictory data.
  - Societal bias: this refers to the attitudes or stereotypes ingrained in the researcher's culture and education that can affect understanding and selection.
  - Safety boundaries: i.e. the mental maps of risk and safety that can influence choices.
  - Under-representation of minority classes: this is a bias due to the fact that certain type of data or systems may not represent all the cultures/minorities
  - Validation of data labels: this occurs when data labels are validated either by a human or by a system.
- ➔ Presentation and Implementation
  - Flawed interpretation of results: this occurs when there is voluntary (e.g. by the researcher) or involuntary (e.g. given by the fact that the system is flawed or by procedural / habitual behaviours in interpreting the results) manipulation in the **analysis** or reporting of findings
  - Misapplication of models: this occurs when the models are applied to the wrong data/domain

In the following section we will present a case study scenario where Social Media Data is collected for an emergency, analysed using a machine learning algorithm and the results are presented to the user using a visual interface.

A Scenario

An emergency management team decides to use social media to understand the events related to the terrorist attack in Istanbul. They use a system that collects social media data legally and in line with the terms and conditions of Twitter. The Twitter data they gather will be fully identifiable.

The system gathers data using hashtags such as: #Turkey #Istanbul #ISIS #IS. The system will:

- perform sentiment analysis
- perform social network analysis
- create a network visualization

- starts following users that post relevant content

The aim is to understand how sentiment about the events emerges over time amongst different networks of Twitter user and identify specific users that show extreme emotions and can be, for the content and the sentiment shared, and their social network position, be identified as “threats”.

In order for the system to achieve its aims, it needs to run some Machine Learning algorithms. For example, let’s take Sentiment Analysis. In order to perform Sentiment Analysis, the system will have to be pre-trained on an existing corpus of Twitter data, ideally related to Emergency Management. The training corpus could be old (therefore obsolete) and chosen with a bias (e.g. only Tweets in English related to terrorism and a few other natural disasters): in the training corpus researchers will have annotated each Tweet with a sentiment, thus potentially introducing new bias (e.g. sentiment could be very subjective and culturally different). The ML learning algorithm will use that corpus to create a model, based on rules (e.g. “when the Tweet contains the words ‘I am upset’ the sentiment is negative”) and will use this rules to automatically classify the incoming Tweets into positive, negative or neutral.

In the following table (Table 1) we identify the possible ethics risk associated with the above scenario using the classification provided by Tiell et al. and other risks identified (for the purpose of this analysis we will limit the ethics risks to those associated with the interaction between machine learning and social media, not taking into account more generic risks associated with the use of social media data).

ETHICAL RISK	**IMPLICATIONS**
Data collection bias.	Data is not representative of population that does not use social media or uses a different social media from the one concerned.
Missing or Erroneous Data	The system collects social media data using hashtags. Not everyone uses hashtags but may still use related terms therefore potentially missing relevant data. Intelligent solutions that use content analysis and synonyms for gathering content allow for more flexibility and wider coverage but at the same time can bias the data towards the system “dictionary”.
Misquantified or misrepresented data	The system will make judgements about tweets (i.e. sentiment) that may result in data being misrepresented as the true sentiment may not come across (e.g. sarcasm).
Reinforcement bias	When the system learns that a user is relevant (given the topic and the sentiment shown) it will start following that user to gather more content, thus potentially reinforcing the bias as more data is available from users highlighted as “relevant” Rumours and false information, often spread intentionally by users trying to manipulate the system, may be reinforced.
Under-representation of minority classes and societal bias	Data is not representative of population that does not use social media and this will introduce an under-representation of minority classes. Moreover sentiment analysis systems are language dependent and if a sentiment analysis system is not able to cope with a specific language/dialect this will introduce a societal bias.
Validation of data labels	Given the high variety of topics and domains discussed on social media, the training set used as an input by the system may not be the most relevant for the topic under investigation. If the validation of the training test has been done automatically, this will introduce a biased linked to the fact that another

	algorithm has been used; if it is done manually it will be biased due to human factors. Mislabeling of training data can generate or exacerbate other biases. Rumours and false information can be taken as truth by the system and used to train its algorithm.
Flawed interpretation of results	The system interpretation of data will be presented in a graphical form, thus potentially distracting the user from whether the data is misrepresented.
Data validity/availability bias	On Social Media, users or social media providers can remove information they posted, simply because they changed their mind or because they realise it is dangerous information or it is possibly infringing privacy regulations. Given the fact that the system collects data from social media providers and stores it for analysis, data that has been later on deleted can be still visualized/available in the system. Moreover deleted may be still part of the training set, therefore biasing the system judgement using data that should not be available.

Table 1. Ethical Risks in Machine Learning and Implications for Social Media Analysis

MITIGATION STRATEGIES

Mitigation strategies for the risks highlighted before can be introduced in a social media analysis system using a privacy by design framework, where all the privacy and ethics risks are considered and appropriate mitigation strategies for the case study are implemented.

The main mitigation strategies we have identified are:

- being *transparent*
- being *interactive*
- being *robust against manipulation*
- being *reactive*

The main mitigation strategy to ensure an ethical approach to Machine Learning for Social media data is to have a *transparent algorithm*, that provides users with means to monitor and understand the system internal working. Having a transparent algorithm will enable users to spot biases or mistakes and adopt corrective actions. For example, whilst data collected on social media may not be representative of all society, methods for quantify and control for selection bias can be adopted, using demographic inference techniques and looking at the information provided weighted by demographic (Culotta, 2014) to be aware, if not necessarily adjust for the bias. Corrective actions can also be taken to cope with missing data: various mitigation strategies exist ranging from using statistical methodologies to capture generic trends to develop remedial techniques (Robins et al., 2004; Sadikov et al, 2011).

Another important strategy is to have an *easy, flexible, interactive interface* that supports the user in investigating the data and provides full trace back of information a conclusion is based upon, with supporting evidence. Ideally an interactive interface will also provide means to interact with the algorithm, to report false positives or false negatives and improve the system performance.

To support ethics and privacy a machine learning system for social media should be *robust against manipulation*. For example, a sentiment analysis system for social media should be able to identify sarcasm, as sarcasm is a factor that can completely change the polarity of a sentence (Maynard et al, 2014). Being able to understand the sentiment and nature of a social media message very important: in 2010 a UK citizens was arrested under the Terror Act as authorities monitoring Social Media spotted a message he sent on Twitter regarding an airport (http://www.independent.co.uk/news/uk/home-news/twitter-joke-led-to-terror-act-arrest-and-airport-life-ban-1870913.html). This is a clear case where a police force monitored Social Media for terror relevant messages and flagged up as highly suspicious a sarcastic message. Another example of robustness against manipulation is the ability to cope with rumours and false information. In order to do so, multiple solutions could be employed, from a user verification and trustworthiness algorithm to multiple sources verification of a news. The sources used to verify a news could be official sources or could alternatively be other

Social Media users. In 2010 Mendoza et al published a work following the propagation of 'confirmed truths' and 'false rumors' on Twitter after an earthquake in Chile. Mendoza, Poblete, & Castillo, 2010 followed the propagation 'confirmed truths' and 'false rumors' on Twitter after an earthquake in Chile. They found that approximately 95.5% of tweets validated the 'confirm truths', and only 29.8% validated the 'false rumors'; while more than 60% denied or questioned them (Mendoza et al., 2010).

Finally, the system must be *reactive*, i.e. able to quickly act in response to a situation. For example, when a social media post is deleted, the system must ensure that the message is deleted from all its storage and from its training set, and rules learnt on the basis of that message should be "flagged" as potentially biased and needing confirmation. To avoid the risk of using "deleted" data in the learning and predicting process, the system should run on live data.

Whilst we have highlighted above generic mitigation strategies, it is useful to go back to our case study scenario to see how those mitigation strategies should be implemented in practical terms.

MITIGATION STRATEGY	POSSIBLE IMPLEMENTATIONS
Data is not representative of population that does not use social media or uses a different social media from the one concerned.	The system should make use of the metadata available and of demographic information to allow the user to view information faceted by parameters, i.e. Based on location, demographic information etc.
The system collects social media data using hashtags. Not everyone uses hashtags but may still use related terms therefore potentially missing relevant data. Intelligent solutions that use content analysis and synonyms for gathering content allow for more flexibility and wider coverage but at the same time can bias the data towards the system "dictionary".	The system should have powerful search operators to enable capturing wider content than hashtag, provide users with means to constantly monitor the used synonyms and keywords, provide means to easily remove keywords from the search.
The system will make judgements about tweets (i.e. Sentiment) that may result in data being misrepresented as the true sentiment may not come across (e.g. Sarcasm).	The sentiment analysis should be, if possible, customized for the domain, and offer a range of sentiments instead of a simple polarity. Advance techniques for sarcasm and irony detection should be adopted.
When the system learns that a user is relevant (given the topic and the sentiment shown) it will start following that user to gather more content, thus potentially reinforcing the bias as more data	The user interface should allow visibility of evidence (i.e. Tweets and networks relationship to illustrate why a user is considered relevant). The user interface should provide users with

is available from users highlighted as "relevant" Rumours and false information, often spread intentionally by users trying to manipulate the system, may be reinforced.	means to constantly monitor the followed users and correct the monitoring if needed (e.g. Unfollow a user). The user interface can provide means to manually annotate message to reflect human analysis (e.g. Annotate a user as a divulger of false information).
Data is not representative of population that does not use social media and this will introduce an under-representation of minority classes. Moreover sentiment analysis systems are language dependent and if a sentiment analysis system is not able to cope with a specific language/dialect this will introduce a societal bias.	The user interface should clearly highlight if any data is missing from a representation, for example if sentiment analysis is available only for English messages but the system collects all languages, the user should be made aware of the bias. Simulations should be run on multiple datasets to determine whether the same results are produced for different populations or scenarios.
Given the high variety of topics and domains discussed on social media, the training set used as an input by the system may not be the most relevant for the topic under investigation. If the validation of the training test has been done automatically, this will introduce a biased linked to the fact that another algorithm has been used; if it is done manually it will be biased due to human factors. Rumours and false information can be taken as truth by the system and used to train its algorithm.	The internal workings of the algorithm should be explained to the user and the user should be able to provide custom training material for the algorithm. Possibility to feedback to the learning module should be provided to improve the system's effectiveness.
The system interpretation of data will be presented in a graphical form, thus potentially distracting the user from whether the data is misrepresented.	The user interface should choose visualisations that highlight the data dimensions but do not hide any missing data or misrepresent the available data.
On social media, users or social media providers can remove information they posted, simply because they changed their mind or because they realise it is dangerous information or it is possibly infringing privacy regulations. Given the fact that the system collects data from social media providers and stores it for analysis, data that has been later on deleted can be still visualized/available in the system. Moreover deleted may be still part of the training set, therefore biasing the system judgement using data that should not be available.	The system should, whenever possible, perform checks on the validity of the information it stores. For example, when receiving a notification from the Twitter API that a tweet is deleted, the system should delete the tweet from its internal storage.

Table 2 - Mitigation strategies for Machine Learning risks and Possible implementations

CONCLUSION

This paper started by reflecting on the use of social media during emergencies and how, given the large amount of data available and the need for fast, flexible, agile reaction, intelligent systems that categorise and analyse social media content are often used. However, the combination of social data and automatic or semi-automatic Machine Learning technologies to understand and filter the data can exacerbate existing privacy and ethics risk related to the use of social media in emergencies and also introduce new ones. To better understand how to develop a new generation of Machine Learning-based social media analysis tools to support emergency management, an analysis of the risks and mitigation strategies has been performed, using as an example a case study scenario of sentiment analysis on Social Media. This examination will be used as part of the iTrack project to guide the design and development of a solution for social media analysis in iTrack.

ACKNOWLEDGMENTS

This work has been carried out as part of the iTrack project. The iTrack project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 700510".

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Translation in Personal Crises: Opportunities for Wearables Design

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ABSTRACT

This paper reports on a qualitative study exploring personal crises that emerge during transitions. Personal crises, like crises caused by natural disasters, often lead to new behaviors and opportunities for technology appropriation and design. Through interviews with 14 military veterans re-integrating into civilian society, we find that the veterans' transitions involve several impediments related to translation work—the process through which people make sense of the conflicting rules and norms between former and present social realities. We developed guidelines for the design of new wearable devices that can aid veterans in the translation process by proposing a six-fold schema of design criteria for wearables—detection, nudging, portability/proximity, inconspicuousness, connectivity, and reflection—to empower veterans in managing personal crises, fostering resilience, and creating normalcy. Finally, we develop the concept of *identity creep* to explicate these translation-breakdowns.

Keywords

Transitions, personal crises, identity, identity creep; sensors, wearables, design.

INTRODUCTION

When people experience disruption, the routine practices on which they typically rely may change drastically (Quarantelli, 2005). Disaster studies have explored how people affected by natural disaster, such as earthquakes, modify their routine behaviors to restore normalcy (Dynes, 1970; Mileti, Drabek, & Haas, 1975). Conceptualizing the restoration of normalcy through the context of natural disaster is a sound analytical frame; however, it falls short in studies where crises extends beyond settings of natural disaster, such as personal crises brought on by the death of a loved one, experiencing a chronic disease, or job loss.

In this paper, we explore the personal crises experienced by United States (US) military veterans during their transition back into civil society. The veteran transition experience is complex, as they must often negotiate several personal crises at once, such as post-traumatic stress disorder (PTSD) and traumatic brain injury (TBI). Research suggests that of the 19.6 million veterans living in the US today (Bureau, 2014), 22 veterans commit suicide daily (Times, 2012), and PTSD affects up to 31% of Iraq war veterans (NIH, 2015). Moreover, and what has received less attention, veterans also experience a crisis of identity (Collins, 1998), which becomes entangled with the other personal crises they face in transition. That is, when returning home from military service, the rules and norms of the civilian world conflict with the rules and norms of the military.

Whereas recent scholarship in crisis informatics has focused on the use of information communication technologies (ICTs) during disruptive events as caused by natural disaster and earthquakes (Mark & Semaan, 2008; Palen & Liu, 2007; Palen & Vieweg, 2008; Vieweg, Hughes, Starbird, & Palen, 2010), the personal crises veterans experience are difficult to detect (Saleh, Saltmarsh, Favarò, & Brevault, 2013) and often require a number of resources to facilitate recovery and restore normalcy (O'Sullivan, Kuziemsky, Toal-Sullivan, & Corneil, 2013). Previous studies of veteran transition have also explored how veterans appropriate mobile ICTs to seek and provide mentorship (Semaan, Britton, & Dosono, 2016; Weick, 1995), manage identity and personal disclosure

(Semaan et. al, 2017), control emotions (MacLean, Roseway, & Czerwinski, 2013), and for PTSD-detection in clinical settings (Fletcher et al., 2011; Webb, Vincent, Jin, & Pollack, 2013). However, to our knowledge, few studies explore in situ design opportunities for sensor devices, such as wearables, to aid veterans in the important translation work—whereby people make sense of conflicting rules and norms—of managing personal crises.

Through a qualitative interview study, we uncover several issues that veterans experience in adapting to the civilian world, and how wearable technology and its design present rich opportunities for augmenting current issues faced in struggles to develop a new normal. We find that the issues they experience relate to difficulties translating between the rules and norms of military and civilian social structures. We introduce the concept of *identity creep*—when previous rules and norms creep into the present, thus creating moments of breakdowns in translation. To address this, we analyze issues that emerged from interview data to inform design criteria for wearable devices, which have the potential to empower veterans in engaging in translation work.

LITERATURE REVIEW

Personal Crises, Transition, and ICT-use

In the aftermath of a personal crisis, people undergo a transition process—a period of adjustment whereby people cope with changing routines, relationships, and roles (Schlossberg, 1995). Importantly, one of the major obstacles experienced in transition relates to emergent crises of identity.

Goffman (Goffman et. al, 1978) describes how identity is a social construction whereby people draw on well-defined rules and norms within a social setting. We often draw on these rules and norms as a means through which we manage other people's impressions of us—or, what Goffman refers to as impression management. The rules and norms that we draw on can vary across different social settings. For example, the ways in which people act in the privacy of their own homes can differ from how they act at work, or in a public space, as the rules and norms of any given setting differ. Identity crises in transition, then, emerge from conflicting rules and norms as people transition from one social setting to an unfamiliar environment.

The process through which people make sense of conflicting rules and norms is a type of translation work—a process where people learn to integrate the rules and norms of their new social structure into their identity. This translation work emerges across three phases—separation, liminality, and incorporation—or, what are known as the rites of passage (Van Gennep, 2011). For the purposes of this paper, we focus on the translation work that emerges during the liminality phase. Liminality is defined as the 'space between'—whereby people learn and make sense of new rules and norms. For example, when a veteran starts a new job, the rules and norms of their present work environment may differ from the rules and norms of their former work environment. Thus, during the liminality phase, people engage in the translation work necessary to make sense of these differences, to incorporate these differences into their identity.

Veterans often experience identity crises caused by the civil-military cultural gap (Erikson, 1994). That is, there exist intense differences between the rules and norms of the military world and the rules and norms of the civilian world require. On the one hand, the social structures of military culture are centered on collectivist values, hierarchy, obedience and control, structured routines, hyper-masculinity, and merit-based remunerations. On the other hand, the social structures of civilian culture are centered on individualism and freedom from authority and control. These stark differences in the social structures of military and civil societies can create various issues for veterans as they engage in the translation work necessary to incorporate the rules of civil society into their new identities. For example, veterans may struggle to make sense of the ways in which organizations promote members in the civilian world. Whereas in the military promotion is based purely on merit and time served, in civilian society promotion can be related to values that are foreign to veterans, such as how well people social network.

Research exploring the role of technology during transitions has explored residential moves (Shklovski, Kraut, & Cummings, 2006), breakups (Massimi, Dimond, & Le Dantec, 2012; Sas & Whittaker, 2013), bereavement (Mancini, Sinan, & Bonanno, 2015), sexual assault, homelessness (Le Dantec & Edwards, 2008), the transition from high school to college (Cummings, Lee, & Kraut, 2006), and gender transitions (Haimson, Brubaker, Dombrowski, & Hayes, 2015). Most relevant to our work have been studies exploring technology use amongst veterans undergoing the transition back to civil society (Franco, 2016). Semaan et al., 2016 found that veterans used social and mobile media as a means to make sense of the rules and norms of civil society and develop identity awareness. Similarly, Semaan, Britton, and Dosono (2017, forth), found that the hyper-masculine norms of military life impacted veterans when disclosing issues while in transition, but that they used online platforms, such as Facebook, to navigate these challenges and connect with supportive resources. Moreover, Franco and colleagues (Franco, 2016) developed a mobile application to help veterans prevent and detect anger issues.

Identity Crises and Veteran Transitions: Towards Opportunities for Wearable ICT Design

Whereas previous work has started to explore the role of technology to help facilitate the veteran transition process, to our knowledge, few studies exist that explore design opportunities for sensor devices, such as wearables, in helping veterans engage in the translation work necessary to manage personal crises and subsequently adapt to new rules and norms while transitioning into civil society.

Previous studies have explored wearable use for mental health recovery and life transitions such as using a wearable to foster identity and self-awareness for children with ADHD (Garcia, Bruyckere, Keyson, & Romero, 2013; Kefalidou et al., 2014), a biofeedback stress-intervention tool (MacLean, Roseway, and Czerwinski 2013), for "Just in Time Adaptive Interventions" (Nahum-Shani et al., 2014), stress detection of depression in college students, and DIY-created applications (Webb et al. 2013; Fletcher et al. 2011; Tan et al. 2010). Other studies include the use of situated and participative enactment of scenarios" in HCI design of wireless devices (Iacucci & Kuutti, 2002), and using wearables to enhance self-reflection (Kefalidou et al., 2014). These studies underscore the promise of biosensors for tracking health information, a practice highly applicable to a wearable device for veterans.

However, existing studies do not use *in situ* commercial technologies and have not focused on translation work. Research exploring the translation work by populations undergoing transitions has found that the liminal phase has negative psychological consequences (Noble & Walker, 1997) and we believe that there exist opportunities to design wearables to aid veterans in this critical process. Obtaining accurate, timely information about situated activity from veterans is difficult and yet critical to detecting and recording behaviors of more and less successful cases.

METHODOLOGY

We use semi-structured interview data of US veterans undergoing re-integration into civil society. Our data is part of a broader study of the use of ICTs by underserved populations experiencing life disruptions. We draw on interviews conducted from May 2015 to May 2016 with fourteen US military veterans. Informants served various deployments in relatively recent US-involved conflicts including Operation Desert Shield, Operation Desert Storm, Operation Iraqi Freedom, and Operation Enduring Freedom.

To ensure a diverse representation of veterans, we recruited from multiple sources concurrently, such as through the Institute for Veteran and Military Families (IVMF) and Veteran Administration (VA); and snowball sampling. Study eligibility was limited to participants who had served in the military. We did not limit recruitment by campaign served or window of time since discharge given our conversations with experts at the IVMF and VA and the literature, which emphasized the longitudinal dimension of the reintegration process, spanning months or years after the initial transition. Participants did not receive compensation for their involvement in the study.

Interviews consisted of semi-structured life histories that ranged from 1 – 4 hours. We conducted face-to-face interviews where the participant felt most comfortable, such as at a café or at home, or via Skype or the telephone. During the interviews, we asked veterans to guide us through their lives before, during, and after military service. We asked about their daily routines from when they were in the military to their current processes, and any issues faced during the liminal stage of their transition. Instead of prompting the veterans about their use of ICTs, we allowed that information to come out of the discussion organically. All informants reported the proficient use of technology. All interviews were audio recorded and transcribed for later analysis.

The process of coding was ongoing, and the research team met multiple times a week to discuss findings in a collaborative coding approach. We conducted inductive and thematic analyses of the data by coding and memoing, using a technique from grounded theory (Strauss and Corbin). Several codes emerged, e.g. PTSD and shame, which related to the issues arising from shift from military to civilian life and veterans' attempts to manage issues. We grouped issues and management strategies into broad themes, through axial coding, and these latter code categories included social rejection and self management.

Our participants comprised fourteen veterans (5 female, 9 male) who served in the Air Force, Army, Marines, and Navy and served in a variety of positions, including infantry, technical infrastructure engineers, and officers. All participants were discharged from active duty between 3 months to 10 years ago. Participants have a wide span of educational attainment ranging from no college to a doctorate degree. Their current employment status is also diverse, from unemployed and full-time student to entrepreneur and IT engineer.

RESEARCH SETTING: A LACK OF ASSISTANCE IN TRANSLATING EXPERIENCES

Veterans experience lack of assistance translating experiences due to the inadequacy of formal transition assistance programs. As a result of the military's pervasive hyper-masculine, collectivist culture and the lack of formal assistance and structure, veterans are unprepared for the social, cultural, and emotional translational work necessary for transition to civil society. They find themselves failing: to find employment, to successfully complete school, amongst a range of shortcomings.

Veterans who experienced trauma during active duty now suffer from mental and physical injuries. Our informants experience a host of mental health issues including PTSD, alcoholism, homelessness, hyperarousal, anger issues, depression, and suicidal ideation. Physical health issues range from TBI and chronic pain to loss of limbs.

Moreover, and as will be described in detail in subsequent sections, veterans also experienced trauma in translating between the rules and norms of military and civilian social worlds, as related to the shift from norms dictated by collectivism, hyper-masculinity, obedience to authority, routinized structures, and merit-based rewards, to norms dictated by individualism.

Informants expressed how formal programs do not prepare or train veterans for the social and cultural skills they need to successfully transition. Our informants felt blindsided by underestimating the extent to which the level of difficulty transitioning would affect their mental, social, and physical well-being. As one participant reported:

"You see that people are changing jobs every 18 months or two years. They can't stick with a job. It's not that they can't stick with a job. But it's that navigation, but figuring out what the truth is. Understanding what you're good at. Trying to get the organization to map the skills you need. Whereas with the military they are looking at you as a person, instead of a headcount. It's a huge paradigm shift and nobody tells you that everything is going to be turned on its head."

Whereas programs exist to help veterans adjust to their life as civilians, our informants described how formal transition programs such as the Transition Assistance Program (TAP), fall short. Similarly, participants described how the VA did not prepare them to re-enter society, providing only generic job-seeking guidance. Programs leave out critical reintegration preparation such as social literacy skills. Informants elaborated on how the programs fail to address organizational culture, networking, and facing the translation of military norms to civilian norms in the context of work. As such, formal assistance is not available to help them cope with the emotional side of adapting to civil society.

RESULTS

Through the analysis of informant accounts, we discovered that various personal crises emerge as veterans grapple with their changing identity and circumstances. Their efforts to live productively between two worlds involves translating between the norms and rules governing their former and current social worlds. Reconciling two worlds aggravates implicit tensions and are experienced as triggers, or stressful events characterized by unpleasant emotional upheavals (Noble and Walker, 1997). In the sections that follow, we expound on the informant accounts of issues in transition, and then focus on how issues could be addressed with the use and design of wearable ICTs, illustrating opportunities for the design of wearable ICTs that can help people undergo the translation process while in transition

ISSUES IN TRANSLATION WORK

Social Rejection in a New Social Reality

In this section, we discuss how veterans encounter difficulties generated by conflicting rules and norms related to social rejection. These social rejection issues include: *difficulty maintaining and forming relationships because of stereotyping and stigma* and *difficulty maintaining military relationships because of loss of camaraderie*.

Difficulty Maintaining Relationships: Stereotypes and stigma

Social rejections can act as triggers for personal crisis, and occur when relationships crumble because of the difficulty translating military-informed cultural norms of relationships, active duty experiences, and skills to a new social reality. When relationships between veterans and their families or significant others were not strained or complicated by outright hostility, they were tense and uncommunicative from lack of understanding of each others' respective norms and rules. As conveyed by P7, stereotypes of military members was a cultural mismatch between her own and her civilian colleagues' "preconceived notions" about her identity:

"I think the biggest problems I've had are just fitting in. I fit in just fine in the military. I kept up with the guys. That doesn't seem to fit as well on the civilian side. …People aren't very accepting and they get preconceived notions about you. Some love you, then others think you're all baby killers."

In the context of medical relationships, veterans had issues communicating psychological health needs when the hyper-masculine norms and rules of strength, pride and hiding weakness led them to deny mental health problems because the doctor's norms and rules of communicative transparency by talking about psychological health concerns (what veteran norms consider "weaknesses"). Further, the conflicting norms of civilian doctors and veterans relating to identifying and treating health needs emerged as the issue of a stereotyping P13's issues and subsequently mistreating her PTSD:

"In their infinite wisdom, they put a single female with depression issues and PTSD into a mother's post-partem depression group. That's just asinine to put me into a lumped in depression group with all these people who were talking about how they feel after they had their kid."

Furthermore, family members were not always sympathetic to the veteran's experiences and do not understand that their child's experience is a rational response in the face of unreasonable circumstances of the liminal phase, where the social reality of their military experiences creeps into their civilian social expectations, relationship formation and maintenance, and mental health disruptions. P9's parents disparaged her experience and created relationship tensions:

"My parents are not very supportive in this matter, and my dad called me and told me to stop acting like a child."

Family members would infantilize their grown children, denying their emotional or mental competent in coping with health issues, further stigmatizing veterans' valid experiences of traumatization and choking a dwindling source of trusted social support.

Our informants faced communication breakdowns that ranged from language barriers and cultural communication misfires to stereotypical and stigmatizing criticism, to skepticism about informants' technical competency. This judgement of a veteran's mental health, work ethic, and wartime experience by family members, health providers, and workplace colleagues caused conflict and feelings of social rejection.

Difficulty Maintaining Military Relationships: Loss of Camaraderie

Informants described issues related to the loss of camaraderie in the civilian world. One informant, for example, compared the tensions of translating the different "mentalities" of military and civilian interpersonal relationships:

"I liked military life. There's a lot of BS that goes with it, but I'd rather be around someone who was in the military. [Civilians] want to throw you under the bus for a 10 cent raise." [P7]

Often, veterans would only talk to people who they perceived would understand their experience because they anticipated these translational obstacles and the ensuing issues that emerged:

"I would only talk to the people who would understand military life. I couldn't talk to close people to me. My mom, my dad, or my brother, they didn't understand that I carry around this semi-automatic gun, I'm going in kicking doors down and doing this really dangerous stuff. They didn't really understand what I saw on TV. The crazy bombs and the shootouts, they didn't understand the normal day to day experience." [P2]

The conflicting norms about how to relate to others contributed to social rejection and isolation which emerged for veterans as the issue of a dearth of camaraderie. Six of our informants expressed the feeling of loss as a need for camaraderie which resulted because of the cultural breakdowns in how to form social relationships.

"Just trying to get that network back, I mean I missed having the camaraderie, you know it's like who's going to get coffee this morning, you know, hey I'm going to get lunch who wants something. ...It's just been a huge, gap in my life since leaving. People come and go at work and you're lucky if you get a good morning out of them." [P2]

Social rejection was a serious issues that came from a breakdown in rules and norms around how communicate past experiences of war to significant others and present feelings and thoughts that could be mental health concerns to medical providers, and made it difficult to climb the professional ladder because of different values of merit and reward systems in producing economic value and participating in the workplace, and to relate to others intimately in experiences of friendship called "camaraderie" in military norms, rules, and cultural practices.

Self Management and Self Control

In this section, we discuss how veterans experience issues that emerge from the conflicting rules and norms differentiating the military and civilian worlds as related to self management and self control. Through our analysis of informant accounts, we identify several issues making it difficult for veterans to engage in translation work necessary, including: *betrayal and alienation, difficulty identifying internal states,* and the *loss of structure.*

Betrayal and alienation: Ambushed by a lack of control over body and mind

Twelve information described suffering from multiple psycho-social issues in tandem, ranging from PTSD to suicidal tendencies. These issues stemmed from their experiences in the military. For example, one informant who was sexually harassed suffered from assault trauma as well as self-inflicted injury:

"I had a very hard time, I was sexually harassed, it was swept under the rug. It was just a shitty, shitty, time…That morning I decided to shoot myself...I missed my heart by a couple of centimeters. I messed up my lung, and I had three chest tubes…."

While in transition, our informants experienced a lack of control over basic physical and mental needs. That is, their experiences in the military transferred to the civilian world, and they attempted to translate their experiences by drawing on the norms of military society. P8, an African American female veteran, described how she reacted to situations in the civilian world based on her experiences in the military, thus reacting to situations by drawing on her combat experiences:

"I would try to think first, then act. But with my training, I would react first, then think. Any sudden, unexpected noise in an environment would make me afraid."

This alarming, emotionally overwhelming experience of involuntary surrender of sovereignty over one's own thoughts and actions alienates the veteran from herself. Self management becomes difficult, then, because it is impossible to establish a foundational level of trust when frequent, repeated betrayals of body and mind in reaction to social and environmental contexts ambush their plans. In other words, our informants described how behaviors formed through previous military experience undermined their sense of agency:

"You don't have to tell someone if they ask, it's supposed to be your choice, but the way PTSD works is that it makes you do things differently."

Our participants cited thunder, rapid movements by family members, large crowds, and fireworks that caused emotional upheavals leading to uncontrollable behaviors:

"When I went home, it was July and I had already been blown up twice at that time. Fireworks were not my cup of tea. Being in Louisiana around July, they go off all the time and it doesn't matter. That was really intense for me. Dealing with that emotionally was really intense." [P2]

Betrayed by social understandings of reality carried over from her previous military experience, uncertainty festered creating the emotional tolls of frustration and anxiety. Previous rules and norms that successfully predicted danger break down when confronted with fundamentally different social realities. She no longer can manage her thoughts and actions, and fears for those around her, as well as struggles to understand these disruptions, especially their seemingly unpredictable onsets. Many veterans get "ambushed" by PTSD symptoms of intrusion (Sherman, 2015):

"When I was in Iraq, we heard a lot of improvised explosive devices (IED). …We heard a lot of these explosions all the time. … I'm working and my back is to the window, and I hear this roar. I didn't know what it was and I jumped under my desk, and I had just gotten back from Iraq and my colleagues come running, and I said, get down, get down, I don't know what's going on! And they said, what's wrong? I said, did you hear that! It was thunder. There's no thunder in Iraq, it doesn't rain! That persisted for years!" [P8]

Control over mind and body is a major issue that requires negotiating new social and environmental realities, given that the disruptions come from the old world-learned schemas creeping into the new social reality, making translation work difficult.

Difficulty identifying internal states: emotional availability

Informants reported having difficulty recognizing the cause of a stressful trigger because the causes are often multiple or the nature of the cause is an inarticulable cultural mistranslation. This issue emerges as veterans draw on the norms of military culture, or hyper-masculinity, which puts a premium of stoicism and impassivity, where hiding weakness is a source of pride. P8 describes how she had to repress emotions and identity in the military and acknowledges that the military likes to "pretend things don't happen":

"For a female I always said that you either had to be a lesbian, you either had to be a bitch or you had to pretend nothing bothered you. So I had to put myself in a category because being nice was not really going to work for me."

Few veterans are aware that the military's masculine culture dictates values of impression management such hiding weakness by denying issues through restrained disclosure:

"I went to a counselor to see if there's something wrong with me. I went to her and I wasn't ready to admit that I had PTSD. I was in denial, I didn't go for treatment..."[P7]

As a result of this bottling up, informants described difficulty connecting with others, because they would not or could not talk about their experiences. This results in a coping mechanism of becoming emotionally unavailable. As described by P8:

"As far as emotionally, dealing with not really having the people you could talk to about that understand your everyday experience when you were in the military, I didn't have any of those in my life."

Further, veterans often experience difficulties with self-imposed isolation as a response to this emotional unavailability, compounding issues cited in the previous section on social rejection in a new social reality. Emotional control, a norm of military culture, makes translation work difficult as people continue to draw on hyper-masculinity rather than seek support and disclose their struggles.

Loss of Structure: diminished self-worth from perceived lack of purpose

During their transitions, one of the most dramatic differences between military and civil society related to a loss of purpose. That is, as informants shifted to civil society, they no longer felt that their lives held meaning. The shift from collectivism to individualism created a vacuum in sense of purpose because without the collectivist culture to declare goals, our veteran informants were not used to generating self-direction. Seven informants professed difficulty transitioning based on lack of purpose linked to collectivist imperatives. As described by P6:

"Knowing the mindset of the soldier is that you often do things that don't make sense, but it's part of the bigger picture and you have to do it anyways. Compared to being a civilian, you're doing it for yourself and only yourself. You don't see the big picture of how you're making an impact…"

Thus, informants were drawing on the social structures of military culture when translating their experiences in the civilian world. This created disruptions in their ability to transition as, by applying rules and norms of military social structures to the civilian world, they had difficulty in determining their purpose. As described by our informants:

"I went from being a war hero who got these medals to being a college student who doesn't know how to write papers, doesn't know how to ask for help, doesn't know anything about the civilian world."

In the military, the purpose and goals were clear:

"You knew who was evaluated and very clear who was in charge," whereas "going through the transition you realize you're just a speck in this great big world. You become nothing again."

The liminal pressure applied by transition into civil society requires a translation of an old identity and purpose to a new one, formed in a negotiation with others who co-constitute civilian society. This intersubjective process requires a radical reconfiguration of social reality and the understanding of identity politics. One informant described the experience with language of mourning at abandonment of her identity when forced to suppress her military persona:

"Transition is almost like the death of a career. Once I did transition and I talked to other people, they had the same challenge that I did…You can't really be who you are, you have to put your game face on." [P8]

The abrupt change from a highly-structured environment where "someone who is higher ranking than you orders you to do stuff" to radical freedom made our informants feel unprepared for civilian life. In the military, daily activities included structured routines, rigorous physical training, strict adherence to time schedules, a lack of personal freedom, and disciplinary action for infraction. However, civilian life is unstructured and individualistic, representing a seismic shift in motivation mechanisms for veterans from an intimidation and reward model to self-initiated approach. Five of our informants expressed how many aspects of their activities were motivated by a superior. As described by P5:

"You had this drive that wasn't really yours. You have someone who outranks you telling you what to do that can get you in trouble."

This hierarchical and collectivist organization culture which dictated our informants structure and routines made the freedom of civilian life challenging. Ten participants expressed how one of the greatest challenges was the lack of structure. As described by P2:

"What made it difficult was the freedom. Really… I was on my own, and I had to structure my own time."

Difficulty with structure included those who had responsibilities and activities imposed on them by civilian responsibilities. Structuring daily activities even proved difficult for P5, a married man in his mid-40s with children who said his greatest challenge was "… transitioning from a very structured and disciplined environment to a non-structured undisciplined." For P2, a major obstacle for him in civilian life was self-motivation:

"You're depending on yourself rather than a government official telling you what you have to do for the day…When you transition from the military back to being a civilian, you have to have your own drive to get up, go to work, make the best of your everyday life."

Without the structure, participants struggle to navigate for years:

"I'm used to a military structure and it's still hard, even though I've been out for 10 years. I'm going back to school and trying to get my degree, but I don't know what to do, I feel like, a little lost."

The lack of structure in daily activities once provided by the military affected veterans' ability to engage in the translation work necessary to shift from being in the military to assuming their civilian identities.

OPPORTUNITIES FOR WEARABLE DESIGN

Wearable ICTs have gained popularity, largely for managing fitness and health activity. Wearables are commonly equipped with several functions, including: sensors which derive heart rate variability (HRV) and skin conductance to detect a range of cognitive-physiological states such as stress, sleep, attention, and arousal. Wearables also feature real-time trace data markers such as geo-proximal tags "that can accurately stream data that can be stored for retrieval and review at a later time point or transmitted wirelessly for real-time review and analysis" (Carreiro et al., 2015). Wearable devices are also capable of multi-platform connectivity to access a dashboard and visualizations of personal and social network contacts' data either locally or on a web-browser via mobile phones. Further, the culture of quantified self is becoming more mainstream, evidenced by the rapid proliferation of fitness trackers and medical grade devices for personal health management (Martins, 2007; Vawdrey, Hall, Knutson, & Archibald, 2003). Based on the issues faced by veterans, we identified 6 wearable features that enable veteran resiliency in transition: detection, nudging, portability/proximity, inconspicuousness, connectivity, and reflection.

Detection

Wearable devices have stress and emotion detection capacity. Sensors such as electrodermal activity (EDA) and photoplethysmogram (PPG) sensors allow algorithmic detection of heart rate variability (HVR) and arousal, physiological events that are correlated with stress and agitation (Mark, Wang, & Niiya, 2014; Tan et al., 2010).

In our study, we found that people had difficulty detecting issues they were experiencing. For example, they experienced social rejection from the projected stigma of colleagues, family, and friends, and feelings of loss of camaraderie. As reported by P7 and P13, among others, the stigma and stereotypes projected by colleagues, family, and the masculine military culture rendered their experiences as illegitimate and irrational. They need for a way of legitimizing the experiences as rational and "real." Without objective measurement of physiological events and an ability to view mental and physical reactions over time, personal health becomes intractable and even invisible; that is, not easily detected by others, including close friends, family members, or even the individual herself (Semaan et. al 2017, in press; Van Kleef, 2009). Critical events, such as the PTSD-episodes and emotions that prove initially difficult to communicate reported by our participants, are experiences that are often amorphous and imprecise. For example, detection and documentation with physiological data can help lessen the denial of PTSD and assist with the issues of loss of control, by providing a visual and visceral report of bodily activities.

Further, those who report trouble dealing with emotions and mental states like nostalgia, loneliness, and purposelessness, can use detection features to capture the lived experience coupled with consistent physical data over time. Our results suggested that veterans have a need for camaraderie. They struggle with a need social connection and collaborative sense-making of a new social reality. Through detection, veterans can use the wearable as an artifact that makes visible the invisible emotional pain and labor that was previously undocumented in this translational work (Star & Griesemer, 1989). In this way, the wearable has the potential to serve as a neutral third party in the negotiation of veteran's relationship with family, medical team, and social support resources, those belonging to a different social reality than the veterans.

Nudging

A smart wearable device can detect stress and depressive states above or below a given threshold, or in a specified triggering location or situation, and notify the wearer through vibration signals, colors, or other modes of communication. For veterans immersed in a masculine culture, our results indicate that veterans have trouble dealing with the anxiety and paralysis that accompanies repeated, unpredictable, emotionally overwhelming situations. Our results showed that people were unaware of their feelings and reactions to social and environmental stimuli. Also, because such ambushes trigger a “fight or flight” mechanism, veterans are either fighting or fleeing so cannot mark the moment of crisis in real time. These emotional events are often inarticulable during as well as after the event. For example, many reported they feel a loss of control, and they were trained to “react first, then think.” This is not uncommon; patients often express their emotional pain through physical symptoms, especially those who have trouble articulating themselves (Nahum-Shani et al. 2014; A. Smith 2015) such as in a masculine culture of non-disclosure and restrained performance of emotions of the military. These reactions and inability to identify mental states or emotional sensations makes it difficult to manage them, a highly disruptive situation for many of our informants.

A smart wearable device can detect stress and depressive states above or below a given threshold or in a specified triggering location or situation and notify her. That is, the algorithm adjusts to the baseline physiological profile of a veteran, and can nudge them when a threshold is reached or a trigger location is entered to helpfully prompt the awareness of the veteran. The nudging feature can train on the user-input data, such as logging a stressful work event, or feeling isolated at home, and learn to nudge the wearer if their physiological data indicates a neurophysiological correlate of, e.g., a depressive state, anger, and anxiety. User-applied tags for each state will train the device, pairing subjective input with objective data such as HRV, geographic coordinates, or breathing rate. Over time, the nudging mechanism conditions the wearer’s emotional availability through self-observation.

Portable with proximal connectivity

A wearable device is “always on, always connected.” It can gather geographic location data using geographic coordinates and user-input made available through mobile GPS and check-in apps, e.g. Yelp. Our results show that place and location can be triggers for veterans. The locations that cause issues are usually uncontrolled environments ‘in the wild,’ such as public spaces. For example, a grocery store setting with as a busy, crowded space, or a family gathering where loud sounds are frequent can trigger anxiety and PTSD symptoms. Because of this unpredictability that can culminate in an experience of betrayal and alienation of the body and the mind, veterans have difficulty retrospectively remembering the context of the trigger events, which causes difficulties in accurately reporting their symptoms to a medical provider.

Geolocation data can address these reported issues of unpredictability, alienation, and documenting trigger environments, working with detection features of the wearable ICT. The mobility facilitates the detection of emotional states that the veteran cannot make immediate sense of by offering “on the fly” documentation, directing addressing the need to avoid retrospective bias associated with reconstructive memory during common trigger contexts. Further, continuous, portable monitoring can afford a sense of omnipresence of friends and social supporters. That is, the physical sensation of a wearable is consistent with extant therapy approaches, such as therapeutic “grounding” techniques (Coffey, Schumacher, Brimo, & Brady, 2005). For example, a smartwatch has the potential to act as a reassuring presence, that the veteran has continuing support in every environment, regardless of time or situation.

Inconspicuous

There is a widespread use of wearable devices use like smart watches and they are non-invasive, looking not like a medical device but a cultural item, e.g. fashion accessory or timekeeping device. The devices are small, and blend not recognized as a medical device per se. In our study, we found that the hyper-masculine norms of military culture led to a lack of disclosure (c.f. Semaan et al., 2017). Thus, the discreetness of a wearable empowers veterans in self management and control during translation breakdowns, where they can record experiences undetected until prepared to disclose.

Because a wearable is either concealed (e.g. a GSR-enabled sock (Healey, 2011)) or commonly worn as a mainstream commercial item, it is relatively unobtrusive, and discreet. Veterans express a need for performing normalcy, that is, translating experiences when confronted with social rejection or hyper-masculine cultural conflict. The watch as a commercial, not medical, device provides a sense of fitting in, and is a metaphor for their experience not as a “disorder” but as a valid, rational reaction to traumatic or crisis experiences. To the point, a wearable has the potential to effectively circumvent the stigma we found in our study associated with mental health issues through the widespread use of wearable devices because of its inconspicuousness.

Social connectivity

Wearables can support applications and are compatible with other ICTs such as mobile phones and laptop computers, making it possible to assemble additional technical and social networks of support by integrating social media into a resilience and recovery plan. Social rejection in a new social reality demands social connection for translating that social reality into terms that can be understood. Veterans need ways to find, engage with, and share information and social connection with civilians and military comrades alike. The wearable is compatible with social media applications, and the data it collects can potentially be a source of shared understanding. A veteran that is alienated from family member can use the wearable technology trace data to explain their reality, and to connect with former military compatriots to give back to those that have similar profiles to their own.

Communication plays a pivotal role in mediating isolation and for accessing “just in time” support. It also helps veterans to reach to help veteran peers in turn (Nahum-Shani et al., 2014) and connects veterans with similar experiences. Compatibility with other ICTs makes it possible to assemble additional technical and social networks of support, integrating other mobile apps and social media into the resilience and recovery plan.

Reflection and longitudinal evaluation

The watch can provide event-data for long-term analytics and diary practices, by logging physiological data and user-input psycho-physiological states. The labor of translating military work skills and change in culture weighs heavy on veterans’ ability to manage personal crises. A wearable might help the veterans document episodes of mistranslation, and natural language algorithms cluster the tags veterans impute on these episodes by environment (e.g. “at work”). Thus, these episode-environment tag-pairs and/or geolocation data can help veterans to see patterns of behavior. The dashboard connected to the wearable app (available through a mobile or PC application) then pairs them with other users with similar experience, e.g. veterans who have similar experiences. A “recommended buddy” can help to connect veterans who are struggling with similar issues as well as those who have successfully managed episodes of mistranslation.

In our study, we found difficulty controlling thoughts and emotions during translational breakdown such as in thunderstorm or firework triggers. A wearable and the associated dashboard platform aggregates event data and analyze patterns so the veteran can make sense of these unpredictable, ostensibly isolated, unrelated incidences. Such long-term analytics can help the veteran prepare for a crisis by developing sensitivity to trigger “clues,” especially given the common experience our veterans reported: it takes years to feel that they have made progress in reintegrating. Thus, reflection practices in tandem with physiological data also promotes self-awareness and collective sense-making to translate across the divide of cultural norms and rules by sharing data with trusted others in the present culture (Weick, 1995).

Further, our results show that veterans had difficulty with a lack of structure in their lives after military service. The wearable application and a connected dashboard can provide structure, for example, by proving an option for segmenting a veteran’s day, week, or year into goals to achieve or to schedule activities, including a calendar view. These types of structuring affordances can reflect military structures at first, for example, reward-system with badges that reflect military merits when goals are achieved, and scaffold the veteran’s involvement in scheduling and reporting activities as he or she recovers and feels more independent over time.

DISCUSSION

In our study, we described disruptions that emerge during transitions. Previous studies of veteran transition have explored how veterans appropriate mobile ICTs to seek and provide mentorship (Semaan et al., 2016), manage identity and personal disclosure (Semaan et. al, 2017), control emotions (MacLean et al., 2013), and in the clinical use of sensor-technology for PTSD-detection (Fletcher et al., 2011; Webb et al., 2013). However, to our knowledge, few studies explore in situ design opportunities for sensor devices, such as wearables, to aid veterans in the important translation work of managing personal crises.

To describe veterans’ translation breakdowns, we introduce the concept of identity creep: the episodic breakdowns in translation that occur when previous cultural rules and norms creep into the present. For example, veterans experienced identity creep when triggers such as the sound of thunder or exposure to large crowds in a supermarket caused emotional and mental turmoil, making it difficult to function in everyday civilian contexts. When environmental or social realities come into conflict, intrusive moments such as this are symptomatic of identity creep.

Whereas some veterans have been successful in managing chronic personal crises while in transition (Semaan and colleagues), this is not the norm as indicated by the suicide rate, alcohol abuse, homelessness, and other issues that plague the veteran community. We believe that the affordances of ICTs, especially those with sensory capabilities, can help people understand these conflicts—as the conflicts, whether emergent from identity crises or PTSD have negative psychological consequences (Noble and Walker, 1997).

We suggest ICTs or wearables are not a silver bullet solution. ICT design requires a view of the veterans in a rich, messy context (Viseu & Suchman, 2010). We argue that ICTs like wearable technology are not immediate fixes, but rather have a powerful potential to augment the recovery process of veterans returning from active duty. For wearable technologies to do so, however, a study of the intimate connections of humans and wearables requires ongoing attention to the labors of our informants, such as pen-and-journal diaries and physiological data alike, that are indispensable to the successful maintenance of human-machine interactions. For example, researchers should not discount the power of face to face interactions of veteran mentors that are pivotal in translating work skills developed in the military to civilian contexts. This process has been effective in research on veterans and mentorship programs such as iPeer (Rizia et al., 2015), which involve a combination of face-to-face mentorship and ICT-mediated contact between veterans and support persons.

Further, when it comes to veterans in transition, especially in design involving quantified self, the body–a site of privacy and identity–is the primary source of data generation and collection. For example, issues of privacy were forefront in our informant data. In the civilian workplace, veterans saw disclosure as a liability in veterans' reintegration. Moreover, we note with caution that a wearable device is a status symbol, like clothing or a car, given that it is costly and may indicate in-group belonging. As such, there are both opportunities for improving translation processes with civilians as well as mis-translations because the artifact's symbolic cultural meaning may misrepresent belonging to a social group, e.g. a smartwatch may convey the wearer as technologically proficient and concerned with fitness.

Thus, the design criteria put forth in this paper is contingent on the input, feedback, and opinions of users, and the veteran user should control the ICTs' design to the greatest extent possible. The proposed criterion should be vetted through a participatory design study with all invested parties (i.e., veterans, health care providers, and research team).

CONCLUSION

Veterans re-integrating from civil society experience several chronic crises related to translation struggles, making it difficult for them to return to normalcy: social isolation, body-alienation, and self-management. We illustrate ways in which wearable technologies could help veterans and other populations undergoing similar crises to regain normalcy. The wearable promises to address these betrayals of body and mind through features that have proven to be effective in cultivating sensitivity to and awareness of internal states.

We highlight the importance of expanding research on personal crises and ICT-use during the processes of translation during life disruptions, while cautioning that the labor of transition is not addressed by technology alone. As the veteran population continues to grow, it will become increasingly important for more scholars to focus on this vulnerable and undeserved population.

ACKNOWLEDGMENTS
We thank our informants for sharing their stories and their time. This research is currently supported by the National Science Foundation under grant #1657429. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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Monitoring and Resilience of Critical Infrastructure in the hyper-connected society

Challenges for critical infrastructure resilience: cascading effects of payment system disruptions

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ABSTRACT

Critical infrastructures become more and more entangled and rely extensively on information technology. A deeper insight into the relationships between critical infrastructures enables the actors involved to more quickly understand the severity of information technology disruptions and to identify robust cross-functional mitigating actions. This study illustrates how and why disruptions in the payment system in Sweden could create cascading effects in other critical infrastructures with potentially severe consequences for many citizens, government institutions and companies. Data from document studies, interviews and workshops with field experts reveal seven challenges for collective cross-functional critical infrastructure resilience that need to be dealt with: 1) Shortage of food, fuel, cash, medicine; 2) Limited capacity of alternative payment solutions; 3) Cities are more vulnerable than the countryside; 4) Economically vulnerable groups in society are more severely affected; 5) Trust maintenance needs; 6) Crisis communication needs; 7) Fragmentation of responsibility for critical infrastructures across many actors.

Keywords

Critical infrastructures, resilience, collective resilience, payment system.

INTRODUCTION

This paper identifies and discusses challenges that actors responsible for critical infrastructure management collectively face when disruptions in the payment system cause cascading effects in other critical infrastructures.

Our research interest is to understand critical infrastructure resilience from a coping or recovery perspective, i.e. focusing on the question how actors from different sectors in society together can keep critical infrastructures operational despite disruptions, or how they collaboratively can restore operations after shorter or longer breakdowns or periods of limited service.

Critical infrastructures, information technology and crisis management

Societies rely on well-functioning critical infrastructures such as Energy, Information and Communication Technology, Water Supply, Food and Agriculture, Healthcare, Financial Systems, Transportation Systems, Public Order and Safety, Chemical Industry, Nuclear Industry, Commerce, Critical Manufacturing, and so on (Alcaraz and Zeadalli, 2015). When one or more critical infrastructures break down or provide only limited service, large numbers of citizens, companies or government agencies can be severely affected (Boin and McConnell, 2007; Van Eeten et al., 2011). Breakdowns can be caused by internal factors (human or technical failure), external factors (nature catastrophes, terror attacks) or by failures of other infrastructures as there are many dependencies between critical infrastructures (Van Eeten et al., 2011). Energy and Information Technology or Telecommunications are well-known event-originating infrastructures that generate cascading effects in many other infrastructures, as has been shown in different types of analyses (Van Eeten et al., 2011; Lauge et al., 2015). In times of increasing digitalisation and an ever increasing development towards a digitally interconnected society, security experts argue for more awareness for digital vulnerabilities, more attention for cyber security and a need to educate professionals and citizens on these matters (Hagen, 2016).

In crisis management literature, the challenge of interdependent critical infrastructures has been addressed by means of research on Critical Infrastructure Protection and by means of research on Resilience. Within the research field of Critical Infrastructure Protection most analyses are of a quantitative nature, explaining what interactions might occur or which of them are most plausible or most critical, but not discussing how and why they impact other infrastructures. De Bruijne and Van Eeten (2007) argue that those analyses most often are done from a prevention or anticipation perspective. The aim is to identify risks and allocate resources in order to build a defence against them. According to De Bruijne and Van Eeten (2007) and Boin and McConnell (2007) there are limits to this perspective, especially in the context of interconnected infrastructures, because the volume and complexity of these systems make them hard to analyse, and because the number of defences that can be invested in are not indefinite. As such, there will always be disruptions occurring and critical infrastructure managers do therefore need to balance anticipation (prevention) and resilience (coping/recovery). Resilience research is also interested in studying what kind of interactions can occur in complex interdependent infrastructures, but not with the aim to only identify the most critical relations. Rather, the aim is that operators and middle managers learn about complex system behaviour to enable them to perform real-time resilience, or "*operating at the edge of failure without falling off*" (De Bruijne and Van Eeten, 2007, page 25).

Ansell et al. (2010) argue that resilience of interdependent infrastructures increasingly depends on collaborative responses from actors with diverse backgrounds that may not be familiar with cascade effects into areas beyond and outside their own organisation or sector. Boin and McConnell (2007) and Van Eeten et al. (2011) argue that there is limited empirical evidence of cascading effects across many infrastructures, which makes it hard to foresee which interactions may occur across sectors. Risk analysis, business continuity management and crisis management training are often performed within the context of a single organisation or sector and are seldom addressing the holistic analysis of multiple infrastructures (Van Eeten et al., 2011).

In summary, more research is needed to understand collective resilience in the context of critical infrastructure management. In this study, a contribution is made by focusing on one application area, i.e. how payment disruptions impact other critical infrastructures. Despite the long term efforts of public and private actors in the financial sector in Sweden to identify, analyse and understand risks and to develop routines for preventing and mitigating serious disruptions in the payment system in Sweden, there is still a lack of insight into how the proposed action plans exactly need to be executed and how numerous other actors in society (e.g. citizens, food stores, gas stations, voluntary organizations, governmental agencies and so on) will act in case of a temporary or complete breakdown of the payment system. For instance, several key actors in the payment system have in earlier studies expressed that they will take a larger responsibility than their formal responsibility (MSB-2009-3309, 2010), but it is not clear what this implies and how these organizations actually will act when crisis hits. The payment system has been described as an 'inverted pyramid'. At the top of the inverted pyramid is the broad base of economic actors whose daily activity in the market economy gives rise to payment obligations. This base consists of individuals who use retail payment services provided by banks, and a variety of business enterprises in the goods and service industries. The next level includes very specialized firms, such as brokers and dealers, involved in the money, capital and commodities market, which also rely on bank payment services (Blommstein and Summers, 1998, page 27). Rose and Krausmann (2013) use a similar distinction when dividing the financial system into three different levels: the micro-economic level (individual business or household), the meso-economic level (individual industry or market), and the macro-economic level (combination of all market entities). The authors further state that resilience should be addressed at the microeconomic level as "*the macro economy is based on building blocks of producer and consumer behaviour as underpinnings for macroeconomic considerations stemming from group interactions*" (Rose and Krausmann, 2013, page 74).

Resilience

Resilience, as a term, was discussed by Lundberg and Johansson (2015) who stated that the diverse set of definitions of resilience may dilute the concept and render it meaningless as it has too many interpretations. Both Lundberg and Johansson (2015) and Bergström et al. (2015) list that resilience amongst others can refer to: bouncing back to a previous state, or bouncing forward to a new state, or both; absorbing variety and preserve functioning, or recovering from damage, or both; and being proactive and anticipating, or being reactive (when recovering during and after events), or both. Given the variety of interpretations of resilience, resilience is hard to operationalize into measurable indicators (Lundberg and Johansson, 2015). Lundberg and Johansson (2015) therefore proposed the Systemic Resilience (SyRes) model as a step towards better metrics and a more comprehensive understanding for determining the resilience of a system. Lundberg and Johansson (2015) and Johansson and Lundberg (2010) also address the complexity of determining and improving resilience with regards to a system of systems (e.g. as most open systems are part of other systems, the potential levels of analysis are countless).

In line with the challenges to resilience suggested by Johansson and Lundberg (2010) comes the fact that most systems in society, such as the payment system, depend on several different actors to function properly. Therefore, resilience must be considered from a systems perspective. In the field of resilience, this is sometimes referred to as '*collective resilience*'. Weick and Sutcliffe (2007) argue that loosely coupled systems relying on a '*sensemaking'* process generally are more resilient than tightly coupled systems based on the assumption that all system states can be predicted and safeguarded against possible threats. This resembles distinctions made in safety science between the paradigms labelled Safety I and Safety II (Hollnagel, 2013) where Safety I is signified by the idea that safety can be designed into a system and Safety II is signified by the idea that human adaptability is the most important contributor to success despite inadequate design or insufficient predictive capacity of safety engineers. Weick and Sutcliffe (2007) argue that a dilemma exists in sensemaking: you can optimise for analysis or action, but not both. This dilemma seems contradictory to the requirements of resilience, because Weick and Sutcliffe argue for sensitivity to operations and reluctance to simplify (i.e. an interest in details and scrutinize the situation at hand) and simultaneous blunt and immediate action without thorough analysis. The solution suggested by Weick and Sutcliffe (2007) is that deep knowledge about the system should have been acquired earlier (long before the disruption) so that quick and blunt action based on deep understanding of the system's dynamics is possible in case of disruptions. As more actors may simultaneously initiate a quick and blunt response, a risk is that these responses counteract each other. Weick and Roberts (1993) discuss how attentiveness (heedful interrelating) is key in a resilient group response, i.e. while acting quick and blunt, various actors should pay close attention to how other actors respond and to what kind of system behaviour their collective response leads. Heedful interrelating has been demonstrated in small groups. Heedful interrelating becomes challenging when systems become larger, more interrelated and involve more and more decision makers that do not really know each other and do not understand the impact of their decisions on nearby systems, as in the case of large interdependent infrastructure systems (Ansell et al., 2010). Then these groups of stakeholders may lack swift trust (Weick and Roberts, 1993) and may lack a shared understanding of the situation and a shared vision, which may lead to inferior performance (Berggren et al., 2014). Yet another risk might be organisations or companies who continue putting their own goals ahead of the common good, thus risking initiating counterproductive actions that may hamper the process of recovery from disruptions.

Purpose

One way to increase the collective resilience of the payment system and related critical infrastructures is to increase insight in:

- Expected cascading effects of smaller and larger incidents.
- Consequences of the cascading effects.
- Actors who are affected by these effects/consequences.
- Potential mitigating action strategies.
- Actors who are involved in designing and implementing these action strategies.

When the involved actors develop a more detailed understanding of how the total system of interconnected critical infrastructures behaves, they can more quickly identify incidents and their potential consequences, develop more comprehensive situation awareness and select and execute more suited and more robust mitigating actions. ***This study aims at identifying cascading effects, consequences, actors involved and potential mitigating actions for payment system disruptions in Sweden and explaining their interactions.*** Through document studies, interviews and workshops with field experts, seven challenges have been identified for critical infrastructure resilience in the case of payment system disruptions.

METHOD

Research design

Our research design is based on an inductive research strategy and a qualitative research method. A clear theory on how critical infrastructures exactly are related, and how the many actors involved collaboratively could manage disruptions that create cascading effects in many infrastructures, is lacking. As such, there is a need for theory building rather than theory testing, which leads us to an inductive research strategy (Eisenhardt and Graebner, 2007). From an interpretative perspective, we are interested in exploring the many different interpretations of actors involved regarding what challenges disruptions can pose and how they could be handled collaboratively across the affected infrastructures.

As pictured in figure 1 data sources included document study of prior incidents, interviews with key representatives from each sector and two workshops with respectively national and local actors. In the workshops, actors from different sectors enriched the scenarios in cross-disciplinary group discussions. Data analysis occurred at two moments. Results of the document study and interviews were summarized into two scenarios which in turn were input to the workshops. The output of the workshops was analysed and, in combination with the previous insights from document study and the interviews, seven challenges for critical infrastructure resilience have been identified.

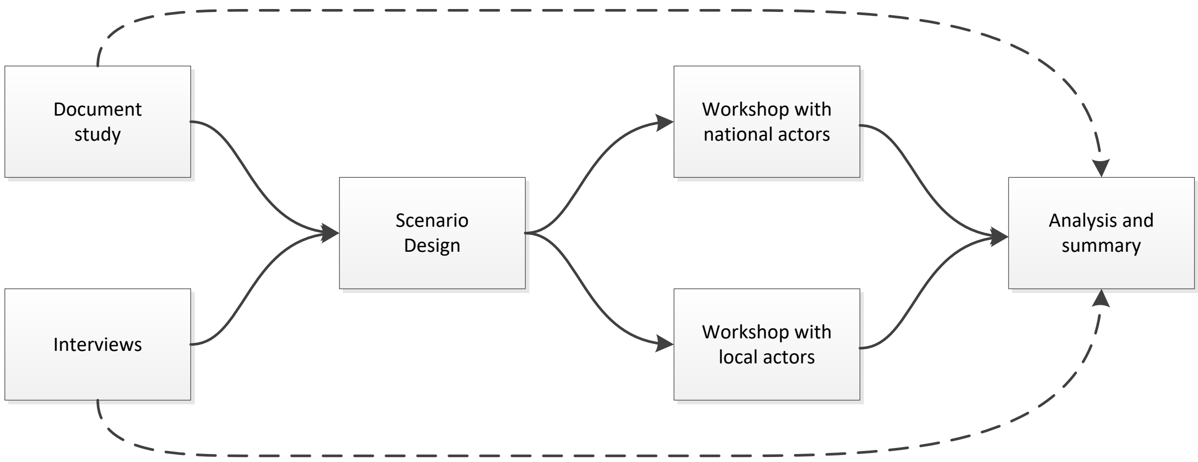

Figure 1: Research design

Data collection: Document study

Three researchers were involved in collecting documents during spring and fall 2016 that described interdependencies between the payment system and other critical infrastructures. Our analysis started from previous work that has been done by the Swedish Civil Contingencies Agency in so called Collaboration Areas where public and private actors from a couple of critical infrastructures had done collaborative risk analysis and development work to increase emergency preparedness at a national level. From these different groups we collected 19 reports discussing risk, vulnerabilities and dependencies. One key study was "*If one falls, do all then fall?*" (MSB, 2007), which was explicitly discussing cross-sectorial dependencies. Through snowball sampling (i.e. identifying interesting reports referred to in the original sample) another 8 reports were included. In addition, we got a number of internal reports from the people we interviewed and from those who participated in the workshops, which brings the total number of analysed reports on 33.

Data collection: Interviews

During fall 2016 six interviews were conducted to complement the document analysis. These interviews aimed at addressing issues that were not discussed in detail in the reports. The interviews were rather open in nature and had as staring point "*if credit card/bank payment would not be possible during 2 days or 2 weeks, what consequences would that have for your organisation/sector*". After follow up questions to dig deeper in what consequences would imply for different people involved, a second part of the discussion would focus on what kind of mitigating actions could be implemented, by the organisation/sector themselves, or in collaboration with others. When selecting interviewees we aimed at acquiring representatives from different sectors. Three interviews were conducted by visiting the organisation (the Central Bank of Sweden, a branch organisation for Swedish Commerce, a municipal security officer) and three interviews were conducted by phone (a gas station branch organisation, a freighting-companies branch organisation, a supermarket). Interviews were conducted by one researcher who took notes and made an interview transcript directly after the completed interview.

Data analysis: Selection and design of scenarios

From the document study and interview transcripts two scenarios were developed. In an iterative process, where three researchers discussed the collected data, scenarios were developed that were expected to have most impact on a large variety of other infrastructures and services. One scenario was "*card payment breakdown in 10 days*" and the other was "*bank transfer disruptions (not all payments are executed, and it is not clear which are executed and which are not)*". Due to space limitations the remainder of our paper will focus on the first scenario. The card scenario was formulated as follows:

- *Card payments do not function in large parts of Sweden.*
- *Electricity is available (and will not disappear, because then the scope of the crisis will be much larger than only a payment system disruption, and the focus on the payment system would disappear).*
- *The cause of problems is disruptions in the telecommunication services between points of sale and banks/card-issue organisations, which will pertain between 7 and 10 days.*
- *Whatever the banks or card-issue organisations try with regard to troubleshooting, disruptions will pertain and card payment is not functioning (or maybe only functioning for very short periods).*
- *All other financial processes and services do function as usual.*

Data collection: Workshop design

Two workshops were organized in November and December 2016. In the first workshop 26 persons participated from a large variety of public and private organisations. They represented the financial sector, food stores, food production and distribution industry, transport sector, counties (responsible for hospital care and having a regional area responsibility for coordinating crisis and emergency management), fuel distribution sector, gas stations, and some governmental bodies responsible for paying sickness/pension allowances.

For both scenarios a rough list of effects of disruptions, consequences for different actors/infrastructures and suggestions for mitigating actions were created as input for the workshops. After a general introduction to our ongoing research project, workshop participants were positioned in three groups with a cross-sectorial composition. Each group discussed one of the scenarios for about 30 minutes, and switched thereafter to another scenario. In the first round they confirmed, enriched and extended the lists of effects, consequences, actors and mitigating actions prepared by the project team. In the second round they received the enriched and extended material from another group and continued with that. In such a way multiple groups of people enriched the scenarios and descriptions of elements and interactions.

Data collection occurred in three ways. First, the groups wrote down notes of what they were discussing on large A3 papers. Secondly, nine project team members were observing the discussions and listening/taking notes. Thirdly, a panel debate was organized at the end of the afternoon where insights from the earlier small group discussions were shared between groups and the project team.

The second workshop used the same starting material, but here there were two smaller homogeneous groups, only consisting of respectively 5 and 6 municipal crisis officers (who have a local area responsibility to coordinate cross-organisational crisis management efforts across societal actors within their geographical area). The two groups did discuss both scenarios independently (i.e. we did not, as in the previous workshop, share material between groups). One researcher and the workshop participants took notes during small group discussions and a concluding debate.

Data analysis: Identification of seven challenges for critical infrastructure resilience

Seven researchers from the project team were involved in a full day seminar in December 2016 where we further analysed the material produced in the workshops and identified the seven challenges. Summaries and texts were shared and collaboratively developed after the seminar and resulted in the descriptions of the challenges presented in the result chapter of this paper.

RESULTS

The results presented in this section summarize our cumulative insights after the second analysis phase as pictured in figure 2, i.e. these insights are based on the document study, the interviews and the two workshops. From our analysis the following seven themes have arisen:

1. Shortage of food, fuel, cash and medicine.
2. Limited capacity of alternative payment solutions.
3. Cities are more vulnerable than the countryside.
4. Economically vulnerable groups in society are more severely affected.
5. Trust maintenance needs.
6. Crisis communication needs.
7. Fragmentation of responsibility for cross-functional critical infrastructures amongst many actors.

After discussing these themes by giving some illustrative examples a section is dedicated to discussing how the interaction between these seven issues easily can create escalation of cascading effects and their consequences, and what actions might be available to mitigate the impact of payment system disruptions.

In the results SWISH is frequently discussed as an alternative payment option. SWISH (www.getswish.se) is a Swedish phone app developed by the six major banks in Sweden that enables private people to transfer money real time between their bank accounts via their mobile phone number. The solution operates completely independent of the card payment infrastructure. SWISH was launched in December 2012 and has today over 5 million users. From summer 2014 you can also pay to companies.

Shortage of food, fuel, cash and medicine

When customers cannot pay by card in food stores, restaurants, public transport, taxi and gas stations the majority of sales can halt dramatically. As phrased during the first workshop: "*Around 90% of all transactions in Sweden occur by card. Many people do not carry cash anymore. More and more stores and most unmanned gas stations are not accepting cash anymore, so card payment is the only alternative. Compared to some years ago SWISH is becoming an alternative, but it is not available everywhere yet*". Consequently, customers might initially postpone their purchases (if they assume the disruption only will last some hours), or might alternatively try to collect cash. When the disruption is not solved within the first 24 hours and the larger public realises that card payments might not be possible for a longer period hoarding of cash, certain food products and fuel might occur quickly. The risk for hoarding was mentioned frequently in the workshops. Descriptions of historical incidents confirm that not much is needed for people to start hoarding. During the financial crisis in Iceland in 2008 people started hoarding fuel and basic groceries when there was a currency shortage in combination with a belief that food importation might cease (Johansson, 2011, page 28). During a 3 day snowstorm in 1998 in the city of Gävle (Sweden) hoarding occurred when food stores did not get their usual deliveries (Lindgren and Fischer, 2011). Similarly, the workshop participants expected that cash in ATMs will run out quickly when everybody tries to get hold of cash as an alternative payment solution. Some customers might be able to pay with membership cards from a chain of stores where they have some credit left in points or money (if these operate independently from banks and if they still can be registered). During a power failure in 2001 in Kista (Sweden) many stores closed as their cash registers and lighting were not working (Lindgren and Fischer, 2011).

As a consequence, food stores might experience a diversity of problems, ranging from an abrupt halt in sales (for non-critical products) to hoarding and consequently shortage of other products. Perishable goods that are not sold might be needed to be disposed in much larger quantities and due to drastic changes in consuming behaviour major re-planning of deliveries could be expected. Similarly, unmanned gas stations might experience a dramatic drop in sales, while manned stations might experience hoarding. For some small food stores, small gas stations or small freight companies a sales stop of one week or 10 days might bring them close to bankruptcy.

Private households might experience no problems at all or severe problems if this situation lasts for several days or several weeks, depending on whether people have alternative payment options available, and depending on their private storage of food. This means that it is not self-evident who needs help, and who not, and what kind of support is needed.

The problem of getting hold of fuel does not differ for private families or for companies (i.e. freight companies, taxi companies). Some larger freight companies might have their own fuel supply at some of the larger bases, but smaller haulage companies, and even the larger ones when traveling long distances, are dependent on local gas stations. Notably, distribution of cash is dependent on fuel supply, and when hoarding of food occurs, people might travel larger distances to get hold of scarce groceries, thereby increasing their fuel consumption (Lindgren and Fischer, 2011).

While our initial scenario mainly focused on food and fuel, the workshops revealed other critical goods that depend on a functioning card payment system. Restaurants and taxi drivers are heavily depending on card payments. Patients visiting a hospital might be able to pay afterwards by invoice, but sales of medicine in drug stores are heavily depending on card payment transactions.

In summary, many citizens might end up in a difficult situation:

- Because food, fuel and medicine they desperately need might be available at nearby points of sale, but they have no viable option to pay for their purchase or,
- due to hoarding, food, fuel and medicine they desperately need might not anymore be available at nearby points of sale.

Limited capacity of alternative payment solutions

Work shop participants and interviewed experts do have low confidence in cash as a realistic alternative payment option: "*ATMs will be emptied in just a few hours*"; "*there is not enough cash anymore in the total system*", "*the physical distribution of cash depends on a few actors and they might not be able to increase the number of transports so quickly*". So, the general belief is that cash as an alternative only is a short term solution for those people who first can get hold of the limited cash available.

SWISH is seen as a promising new alternative, which can easily be installed at a glance for both shop owners and customers: "*Shop owners will experiment with creative SWISH solutions*", "*When the cash register of the small independent gas station where I was working did not work, we let customers pay by SWISH to a private account of one of the employees, and later the money was transferred to the shop owner*". However, concerns are raised whether SWISH really has to capacity to replace regular card payments instantaneously: "*When card payments are 90% of the total flow of payments, it is questionable whether any alternative, like for instance SWISH, could gear up from 10% to 90% instantaneously*", "*the capacity of SWISH might not be able to process all payments, it could go down like the mobile phone networks do in crisis situations*".

Another alternative payment option frequently suggested is to delay payments in different ways, for example by receiving the products now and agreeing to pay later (when shop owner and customer know each other well) or by sending an invoice. These solutions require some kind of trust level between shop owner and customer. As the risk for not being paid afterwards lies with the individual shop owner, it is hard to foresee to what extent shop owners will offer such solutions.

Cities are more vulnerable than the countryside

Workshop participants emphasized that "*it matters a lot when and where the disruptions in the payment system occur*", for example "*just before or just after salary payment days*" or "*on days when there is a lot of turnover, like in December or Christmas times*" are periods where the same disruption can have more severe consequences for either customers or companies.

Similarly, the same disruption might have different consequences in large cities compared to the countryside. For instance: "O*n the countryside a small gas station owner often knows the majority of its customers, and thus will offer them fuel without requiring them paying. Regular customers will come and pay when the disruption is solved as a thank you for this confidence. In a city where the gas station owner does not know the majority of his customers, there is no way you give them fuel without paying. They will never come back and pay*".

Research has also shown that people at the countryside have larger food supplies than people in cities (Lindgren and Fischer, 2011), and in that way cities are also more vulnerable for disruptions.

As a consequence, involved actors from the finance sector, food sector, fuel sector and transport sector handling the situation need to be aware of such particular circumstances in order to understand which parts of society are affected most and why, and in order to adjust their mitigating actions to these particular circumstances.

Economically vulnerable groups in society are more severely affected

Another expectation of interviewed experts and workshop participants is that people who have a poorer economy, also might have less food and fuel reserves and thus are more dependent on instantaneous purchases. Also, it might be harder for these people to use alternative payment solutions (like paying afterwards by invoice): "*paying afterwards by invoice might involve that the shop owner does a credit control, which might imply that is not a viable alternative for people with a weak economy, who might be the ones in need of such an alternative*". As a result, representatives from the local municipalities in the second workshop were convinced that many people who would get into problems would turn to social care in the municipality organisation to get cash or some basic goods like food and fuel. As documented in descriptions from for instance an ice storm in Quebec (Canada) in 1998, which caused amongst other a power failure of 2-4 weeks (different for different areas), up to 140000 people spent one or more nights in shelters run by local government and voluntary organisations. People needed support partly because they lacked power for heating and cooking, partly because they could not get hold of food in grocery stores, and partly because they had economic problems due to the consequences of the ice storm. Local government had severe challenges in securing food for all the people in the shelters (Fischer and Molin, 2001).

Trust and security needs

When analysing the direct effects of payment system disruptions for food distribution, fuel supply and cash shortage in depth, new cascading effects were identified that were related to trust and security. Trust is a crucial building block for financial transactions, the financial system and society at large. When disruptions are enduring and more and more people get in trouble with regard to payment options or attainability of food, behaviour might get more egoistic and possibly aggressive. Challenges identified are for instance: "*Which stores will allow you to buy food or fuel and trust you to pay at a later stage?*", or "*How can massive hoarding of food, cash or fuel be avoided?*". Or as formulated by Frisell (2011): "*We are only 3 meals from anarchy*".

When trust disappears, security risks grow. When resources become scarce it might sound reasonable to start rationing, but the practical implementation of that at the point of sale level is questionable: "*As a gas station owner, it is hard to allow so called prioritised transports to take fuel, while taxi drivers or private families do not get anything. That might create riots and threats*". A similar argument can be made for food store owners.

Another security issue was the increasing use of cash: "*The current system is designed based upon that cash only is a minor portion of the total payments, there are no security resources to guard use of cash at a large scale*". There is a risk for robberies, both for the customer carrying cash, and for the point of sale where larger amounts of cash accumulate.

Crisis communication needs

There is a clear connection between the previous trust and security issues and the need for communication. The more uncertainty, the more trust goes down and in turn security problems might show up. One person framed it as follows: "*uncertainty can be a larger problem than the actual disruptions and shortages*". Another one argued: "*with rising uncertainty and development of rumours communication becomes crucial*". Also the role of mass media was addressed: "*mass media could trigger hoarding if their headlines are too sensational, what is their ethical responsibility in such a situation?; that should be discussed with them upfront*"

Some people argue that detailed information need to be provided which grocery stores, gas stations and ATMs are still open or do have stock left. However, when stock levels drop and only few points of sale with available products are left, the same detailed information could increase hoarding and put individual shop owners at risk. So it is not self-evident what kind of level of detail in the information provided would be desirable.

Fragmentation of responsibility for cross-functional critical infrastructures amongst many actors

A final issue that was raised in the panel debate and got a lot of approval was the enormous amount and large variety of actors that would be affected and involved. In the payment flows and goods distribution flows (of food, fuel, cash and medicine) many actors are serving as a small link in the larger chain. This creates challenges as well: "*there are numerous actors in the chain, and new actors are entering all the time*"; "*it is hard to get to know all of them and establish trustworthy relations with them*"; "*as so many are involved, it can* *be hard to identify where in the chain the problem actually has occurred*"; "*at some parts of the chain the majority of the flow goes through one or very few big actors, i.e. VISA and MASTERCARD in card payments, this might create bottlenecks or strong dependencies on these actors*"; "*a truck is always a part of any chain somewhere and trucks need fuel*"; "*in the coordination of mitigating actions and the coordination of communication to the public this large majority and diversity of actors is a challenge as well*".

Escalation of effects and consequences

During several interviews and during several moments at the workshops doubts were raised considering how and why this scenario actually could occur (i.e. "*Can disruptions last for so many days?*") and whether public and private bodies would succeed in preserving peace in society, or whether panic, hoarding, robberies would take over. Participants had diverging opinions on this matter. Clear is that a total breakdown would not create immediate fatalities, but that increasing uncertainty about when card payment is restored, to what extent cash and SWISH are viable alternatives, to what extent food, fuel and medicine can be acquired without paying now (i.e. by getting an invoice later) and so on slowly might move towards a tipping point where trust of the larger public in concerted action of public and private players from different sectors is degrading. Which in turn would create escalations as hoarding of cash, food and fuel would worsen the situation and put even more pressure on effective crisis communication and maintaining trust (or restoring trust).

Clear communication and (perceived) forceful countrywide action in early stages are seen as desirable, but simultaneously there is no logical actor or forum that would coordinate this. Precious time might be lost initially to get all relevant players aboard, which might influence quality of communication, coordination and lead to increased uncertainty and loss of trust from the citizens.

The need for early communication of clear and countrywide solutions (righteous for everyone) is in conflict with the fact that the crisis might be more severe for certain groups and regions in society, which creates a need for dedicated solutions. These differences need clarification in crisis communication, so the differences are justified and so they do not influence trust in crisis management negatively.

Clearly, there are also strong dependencies between the alternative payment methods. If one of the two primary alternatives cash or SWISH also crashes, all pressure is put one the last option as long as a general solution for paying by invoice (with possibly a state guarantee for shop owners that they will get their money) is operational.

GENERAL DISCUSSION

The seven challenges are on the one hand a clear roadmap of what needs to be dealt with when major payment disruptions in Sweden occur. Through extensive iterative triangulation, the documented effects observed in earlier incidents and described in existing risk analysis have been confirmed by experts as plausible in this scenario and further extended with additional consequences. The result is, to our knowledge, going beyond existing analysis, either by scope (more cross sectorial, beyond the financial sector) or in detail (discussing interactions between several consequences, rather than just listing dependencies). On the other hand, they are only a rough indication of a direction to go, where questions remain how to "put the pieces of the puzzle together" into a realisable action plan if anything like this actually would happen. In this discussion broader reflections are presented considering our current results and some future avenues are sketched how this result can be incorporated in further research.

Are we not prepared?

To our surprise, many of the actors involved who we met in this study do not have clear ready to implement solutions for alternative payment solutions when the regular payment solutions would fail under a longer period of time. Much is invested in risk aversion (i.e. redundancy of services, reserve power solutions), but that serves as an excuse that a real disaster is less probable. Many hold on to the belief that disruptions will only last a short period. Also, when referring to other sectors, there is some kind of assumption that "*others will solve this before it becomes critical for many people*". So, while there are no real preparations for surviving a longer breakdown in their own sector, there is a belief that such preparations have been done elsewhere. There is also low preparedness among citizens that randomly came in contact with our research project. Overall, there is a strong confidence in that the payment system will function, which could backfire when a longer breakdown occurs, as very few seem to be prepared. More research is needed to uncover what viable mitigating actions could be for different stakeholders and how their mitigating actions influence each other and form a coherent whole.

Too big or too fragmented to be coordinated real time?

So many actors! Every time when digging deeper into particular critical infrastructures in the different sectors it struck us how many actors are involved. From the well-known major players to all kind of telecommunication- and information technology service providers who are responsible for bits and pieces of long delivery chains. This myriad of actors creates a situation where each of them has good insight in their own processes, but lacks understanding how their processes relate to critical processes in other sectors. In the food, fuel and transport sector there are a few very big players and in addition very many small independent shops/stations/freight companies. A complicating factor is therefore how coordination between those many independent small actors could be realized. While such small actors could quickly generate innovative solutions and have the local authority to directly implement them, they might simultaneously lack the necessary strength and resources to survive major disruptions. Future research could dig deeper into the pros, cons and different strategies of small shops and large chains in recovering from enduring major disruptions.

Exploring interactions in more depth

It is hard to grasp the interactions between all the infrastructure elements and actor decisions in an oral discussion. Also, our experience while observing workshop group discussions is that experts might have difficulties in identifying and understanding second order effects of critical infrastructure disruptions (i.e. far beyond their own sector) as argued by Laugé et al. (2015). Consequently, in order to create collaborative system understanding, critical infrastructure managers at strategic, tactical and operational levels, might need richer discussion environments. Atkinson et al. (2015) explain that system science methods, such as system dynamics and agent-based simulation modelling can be used to explore decision making alternatives for complex problems. Bots and Daalen (2007) and Caluwe et al. (2012) discuss successful applications of simulation-games that have been applied to explore the complex interactions between multiple stakeholders with partly conflicting goals facing complex policy making or organizational change situations. Daalen et al. (2014) discuss and give examples of applications where role playing simulation games and computer simulations are combined into a powerful simulation environment. Actors, as game participants, can collaborate or compete with each other in different rounds, enter their decisions in the computer simulation and receive the output of the computer simulation as input in their next playing round. Our ambition is to study critical infrastructure resilience for payment system disruptions in such a simulation environment, combining the strengths of quantitative analysis (agent based simulation) and qualitative analysis (observing interaction in role playing games). This simulation environment can become a systems-of-systems model, which in more detail explores interdependencies between technical infrastructures and between mitigating actions of actors handling disruptions in these infrastructures.

Limitations

Our analysis is based on expert opinions from around 37 workshop participants and 6 interviewees combined with 33 analysed reports. Although material was triangulated until saturation occurred (i.e. experts were contributing suggestions that already had been raised in earlier discussions/reports) new insights might arise by conducting a larger number of interviews/workshops. The analysis is also conducted in a Swedish context. Even though we are aware of these limitations, there are several dimensions that are worth pointing towards which we think are of interest outside of Sweden as well. There are many parallels to other western countries considering the degree of societal digitalisation, urbanisation (higher density of people requiring food and heat can be hard to accommodate in case of a severe disturbance), large dependencies on imported goods and food, transportation of food and goods, and fuel for transports. In addition, major credit card providers such as VISA and Mastercard have almost a monopoly position when it comes to card payments. Trust is a psychological feature that is central to any financial system. Many of the challenges mentioned above are therefore valid in (or can easily be adjusted to the respective situation of) many other societies.

CONCLUSIONS

This study confirms the common understanding that critical infrastructures are more and more entangled. Disruptions in the payment system will quickly have cascading effects for fuel supply, transport systems, food distribution and might create severe challenges in some geographical areas or for some vulnerable groups in society. Our analysis of effects, consequences, mitigating actions and involved actors shows that resilience not only is a question of technical measures (i.e. alternative payment solutions, rationing of limited food and fuel resources and offering services to vulnerable groups), but also involves many social communicative challenges (i.e. maintaining trust, preventing hoarding, avoiding panic). An additional challenge is that impact may differ for geographical areas and certain groups in society which means that general measures need to be combined with targeted measures adjusted to the specific needs for these areas and/or groups.

Seven challenges for cross-functional critical infrastructure resilience, for the specific case of payment system disruptions are:

1. Shortage of food, fuel, cash and medicine might occur
2. Limited capacity of alternative payment solutions
3. Cities are more vulnerable than the countryside
4. Economically vulnerable groups in society are more severely affected
5. Trust and security needs to be maintained at different levels
    - Who accepts deferred payments and who will not?
    - How can massive hoarding of food, cash or fuel be avoided?
    - Large amounts of cash at certain places create security risks
    - Rationing of limited resources may evoke aggressive reactions
6. Crisis communication:
    - What services (food stores, gas stations, restaurants, public transport, etc.) are still functioning and which are not?
    - Howe can panic be avoided?
7. Fragmentation of responsibility for cross-functional critical infrastructures over many actors complicates effective coordination of measures and joint communication to the public

The overview of identified short term effects, long term consequences, possible mitigating actions and involved actors and their capabilities and responsibilities provide a sound foundation to explore the relations between these elements in more detail in future research. When the involved actors develop elaborated understanding of how the total system of interconnected critical infrastructures behaves, they can more quickly identify incidents and their potential consequences, develop more comprehensive situation awareness and select and execute more suited and more robust mitigating actions.

ACKNOWLEDGMENTS

This research was supported by Grant 2016-3046 of the Swedish Civil Contingencies Agency.

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Planning, Foresight and Risk analysis

Intelligent fire risk monitor based on Linked Open Data

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ABSTRACT

Every day the Fire department of the Netherlands work hard to save people's lives. Therefore, they have been investing in Business Intelligence approaches for several years, to get more information for accident prevention and accident fighting. In this paper, Linked Open Data has been used as a business intelligence approach for the creation of dwelling fire risk profiles based on demographic data. During the research a Proof of Concept showed the appliance of Linked Open Data for this purpose. However the data have some quality mismatches, such as: outdated, accuracy issues and not 100% complete. Evaluation session proofed that the outcomes show similarities with a fire incident map and the gut feeling of several firefighters.

Keywords

Semantic Web, Linked Data, Open Data, Firefighting, Risk Assessment.

INTRODUCTION

The primary objective of the fire department is to save people's lives. Saving lives is about seconds. Complete information could make the difference. For instance, the maximum response time is determined by Dutch law (Binnenlandse Zaken, 2011). The factors which are taken into account to determine the maximum response time for a building are the type of the building and the year of construction. But the risk of a dwelling fire and the development of a dwelling fire depends on multiple factors. Some of these factors are not taken into account. Therefore, the use of "Business Intelligence" within Brandweer Nederland is an upcoming interest. Investments to harvest data and process data into valuable information have been made since the last couple of years. At the moment, Brandweer Nederland is working on business intelligence, loads of data are stored in data warehouses to get information on accident prevention and accident fighting (Nederland Brandweer, 2014). Besides the approach with data warehouses, Brandweer Nederland is highly interested in another approach: linked open data (LOD). "Linked Open Data (LOD) is a growing movement for organisations to make their existing data available in a machine-readable format. This enables users to create and combine datasets and to make their own interpretations of the data available in digestible formats and applications." (Bauer & Kaltenböck, 2012). Open datasets have grown exponentially (Stellato, 2012). Combining various datasets could provide more viable information needed for accident prevention and accident fighting. For example, research showed that residences which are more and better isolated (A+ Energy Label1) develop another type of fire, once the building is on fire (Schaap, 2013). Therefore, the level of isolation could be used to determine the risk of dwelling fire, and maybe even forecast the type of fire that will develop. The results of combining datasets will mainly be used to organise better fire safety education in specific neighbourhoods because of certain demographics. Therefore such system will be most valuable in preparation phase. The Linked Open Data approach differs from the warehouse approach. Data warehouses and their maintenance are expensive. With linked data one can gather the information from the original source when it is needed and combine it instantly (without the need to use various database techniques such as download and exporting data). Less investments are necessary in the technical infrastructure. The datasets are maintained by the source itself and provided by an API or by files. Combining more datasets means that new outcomes and insights are created or established outcomes and insights change. Moreover, change in outcomes could affect the determined response time or other decisions, which provide the extra seconds necessary to save somebody's life. This study examines whether linked open datasets could be used as a dynamic way to provide the fire department with quality intelligent information.

MAIN RESEARCH QUESTION

Does linked open data provide a qualitative and dynamic way to create a dynamic fire risk profile monitor for cities and neighbourhoods?

- Research Sub Questions:

1. Which datasets are necessary and which datasets are available
2. What is the quality of the data and is the quality sufficient?
3. To what extend is it possible to use linked data to get a solid demographic fire risk profile?
4. To what extend is it possible to create a dynamic linked data system, for the creation of fire risk profiles?

RESEARCH DESIGN

The research questions have been used as a guideline for the research. Depending on the identified datasets and the availability (format availability) of these datasets, the research has been affected. Based on statistical relations from the Fire department Amsterdam ("Handreiking sociaal woningbrandrisicoprofiel"), open datasets were gathered from the World Wide Web. These datasets were combined and linked to each other and used to develop a Proof of Concept, the outcomes of the Proof of Concept were validated by four firefighters from the safety regions Rotterdam-Rijmond and Midden- en West Brabant. Validation was based on their gut feelings and based on an older map with fire incidents (2005-2008) and a traditional fire risk map of the fire department.

OPEN DATA & OPEN DATA QUALITY

Linking data on the World Wide Web is important, because of the exponentially growing amount of data and information available on the internet (Stellato, 2012). Besides the term "The Semantic Web" another term has been around for the last decade "Linked (Open) Data". Heath & Bizer (2011) define Linked open data as a recent development in which all datasets that are freely available on the Internet are interrelated by using semantic rules and techniques in an effort to publish these in a machine readable way and to facilitate analysis in human understandable form.

OPEN DATASETS

Linked Data is about using the Web to create typed links between data from different sources. "*Technically, data has to be published on the Web in such a way that it is machine-readable, its meaning is explicitly defined, it is linked to other external datasets, and can in turn be linked to from external dataset*". (Bizer & Berlin, 2009). In the past years, organizations have been publishing their data in such a machine-readable way. More organizations are willing to publish their data on the web. Together the published open datasets form the global data space.

Berners-Lee, (2006) outlines a set of 'rules' for the publishing of data on the web. Rules to create a single consistent global data space:

1. Use URIs as names for things.
2. Use HTTP URIs so that people can look up those names.
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL).
4. Include links to other URIs, so that they can discover more things.

These rules have become known as the 'Linked data principles', and provide a fundament for the publishing of data adhering to the World Wide Web architecture and standards.

Furthermore, a network of URIs allows the creation of a network of Linked Data, thus contributing to the construction of a global data model, which is the Linked Open Data. (Bellini, Nesi, & Venturi, 2014)

LINKED DATA TECHNIQUES

Resource Description Framework (RDF) is a technique for data interchanging on the web. RDF is a graph-based data model. The core structure of RDF is a set of triples (Subject -> Predicate -> Object). This triple concept is known as the Triple A principle: "Anybody, can say Anything, about Anything". A concrete example of the triple concept applied on data would be: http://example.org/john --> http://example.org/isFatherOf --> http://example.org/george (Cyganiak, Wood, & Lanthaler, 2014).

In addition to RDF there are more semantic frameworks: RDFS & OWL. RDFS (RDF SCHEMA) is an semantic extension on RDF. The purpose of RDFS is to add more expressivity to RDF graphs by adding more complex relations like: class. Subclass and resource types (Brickley & Guha, 2014).

In some cases the expressivity of RDF and RDFS are not sufficient enough to describe the complexity of a data model. Therefore, the web ontology language (OWL) can be used (Dean & Schreiber, 2014). For simple data exchange RDF is mostly sufficient. More complexity could be found for example in ontologies etc.

DATASET QUALITY

Data is only as useful as its quality (Zaveri et al., 2012). The challenge is to determine the quality of datasets published on the Web and to make this quality information explicit (Zaveri et al., 2012)

A popular definition of quality is “fitness for use". Therefore, the interpretation of the quality of any data item depends on who will use these data, and for which task the user intends to employ it. While one user may consider the data quality sufficient for a given task, it may not be sufficient for another task or another user. (Mendes, Mühleisen, & Bizer, 2012)

According to Zaveri et al., (2012), data quality is commonly conceived as fitness for use for a certain application or use case. Datasets on the Web of Data already cover a diverse set of domains, therefore data could be used for specific purposes. Whether a dataset fulfils the information need is defined as “Fitness for use”. Moreover, fitness for use is commonly used as a definition of data quality. (Debattista & Lange, 2014b)

Zaveri et al., (2012) define a Data Quality Assessment Method. A data quality assessment methodology is defined as the process of evaluating whether a piece of data meets with the information consumers need in a specific use case. The process involves measuring the quality dimensions that are relevant to the user and comparing the assessment results with the users’ quality requirements.

Both Mendes et al., (2012) and Ruckhaus et al., (2013) maintain three main quality dimensions and the metrics to make the quality explicit. The main quality dimensions are:

- Completeness
- Conciseness
- Consistency

Besides these three main quality dimensions, the role of trust is specifically mentioned by (Bizer & Berlin, 2009) as a quality characteristic.

Completeness

On schema level, a dataset is complete when it contains all of the attributes needed for a given task. On data (instance) level, a dataset is complete when it contains all the objects for a given task. Naturally, the completeness of a dataset can only be judged in the presence of a task of which the ideal set of attributes and objects are known.

Completeness on data level is named “extensional completeness”. Completeness on schema level is called “intensional completeness”. The extensional completeness (data level), can be measured in terms of the proportion of target URIs found in the output (Equation 1), while the intensional completeness can be measured by the proportion of target properties found in the output (Equation 2). Completeness in this study is about missing extensional and intensional data. Completeness is not necessarily an issue, as long as it is possible to get information of nearby objects to fill in the gaps in the dataset.

$$extensional\ completeness = \frac{||uniq.\ obj.\ in\ data\ set||}{||all\ uniq.\ obj.\ in\ universe||} \tag{1}$$

$$intensional\ completeness = \frac{||uniq.\ attr.\ in\ data\ set||}{||all\ uniq.\ attr.\ in\ universe||} \tag{2}$$

Figure 1; Equations completeness

Conciseness

On schema level, a dataset is concise when it does not contain redundant attributes (two equivalent attributes with different names). On data (instance) level, a dataset is concise when it does not contain redundant objects (two equivalent objects with different identifiers). The extensional conciseness measures the number of unique objects in relation to the overall number of object representations in the dataset. Similarly, intensional conciseness measures the number of unique attributes of a dataset in relation to the overall number of attributes in a target schema.

In this specific research case, conciseness means, that when two attributes or even objects are the same, it becomes harder to choose how to use the dataset. It makes the data set less understandable and more data have to be processed in order to get information (influences the performance).

Consistency

A dataset is consistent when it is free of conflicting information. The consistency of a dataset is measured by considering properties with cardinality 1 that contain more than one (distinct) value. Mendes et al., (2012) have defined the consistency of a dataset for a given property p to measure the proportion of objects that do not contain more than one distinct value for p, with regard to the universe of unique property values.

Error of data

An important aspect of the data is the error in the dataset itself. Errors are hard to locate. Mendes et al., (2012) use another dataset to locate errors. In their example, they use the Portuguese and the English version of DBpedia. By doing a consistency test between these two datasets, they find the differences and thus errors in the datasets.

Trust

A less measurable data quality dimension is Trust. Trust is mentioned by Bizer & Berlin (2009) in order for data consumers to assess the quality of data and to determine whether they want to trust the data. Data should be accompanied with meta-information (provenance) about its creator, creation data as well as the creation method. Provenance information together with a certain authority of the publisher of the data, will give the data consumer an impression of the data quality.

Dataset Alignment

Datasets are provided by different sources and in slightly different ways. Using Linked Data the focus is on RDF because it mainly involves simple data sharing, RDFS & OWL are not used because of their unnecessary complexity. RDF can be requested from the source, mostly by using SPARQL. SPARQL is not used by all open data sources since it is not required. Providing a spreadsheet file is the most used option for exchanging open data, which organizations use to provide data in an Open Data approach. Combining datasets which are provided using different methods is something that one has to keep in mind using Linked Open Data (Miličić, 2011). Structure and logic of datasets differ from dataset to dataset. It is important to understand the structure and logic of combining datasets, otherwise: "*you can end up with a dataset that you think is ready for analysis, but is really utter nonsense*" (University of Wisconsin, 2011).

Linked open datasets provide for example: semi structured data, unstructured data, documents in mark-up languages. The use of such a variety of sources could lead to problems such as inconsistencies and incomplete information (Debattista & Lange, 2014a). Kontokostas et al., (2014) maintain that datasets are of varying quality ranging from extensively curated datasets to extracted data of often relatively low quality.

FIRE RISK DEFINITIONS

There are more definitions of "risk", some definitions only mention realization of unwanted consequences to human life or property, while other definitions mention more aspects like for example harm to business continuity. Watts and Hall (as cited in Hadjisophocleous & Fu, 2004) use the following definition of risk: "*Risk is the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment*". Estimation of risk (for an event) is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event, given that it has occurred. According to Meacham (as cited in Hadjisophocleous & Fu, 2004), a comprehensive definition of fire risk is given as follows: "*Fire risk can be viewed as the possibility of an unwanted fire hazard in an uncertain situation, where loss or* *harm may be induced to the valued, typically life, property, business continuity, heritage, and/or environment*". The key factors include unwanted outcomes or consequences, uncertainty, valuation, and likelihood of occurrence. Building fire risk analysis can be considered as the process of understanding and characterizing fire hazard in a building, unwanted outcomes that may result from a fire, and the likelihood of fire and unwanted outcomes occurring.

As Bukowski & Safety (1996) mention, it is difficult to express risk to life in a way that can be understood by the public. This leads to the consideration of other metrics for risk. Financial loss is the perfect metric for the property related risk, however, the primary focus of fire codes is life safety, which then requires that risk to life must include a measure of the value of human life. Thus, risk to life is usually assessed separately to avoid the difficulty of assigning a monetary value to human life. (Hadjisophocleous & Fu, 2004)

RELATED WORK

Higgins et al,. (2013), researched the challenges and barriers of safety assessment. Therefore community profiles were created based on open datasets. Over 130 datasets were identified for analysis, whether these datasets were applicable to the community profiles. The community profiles were incorporated in a vulnerability index. The purpose of the vulnerability index is to look at factors present in an individual's lifestyle that are known to increase fire risk. In particular, it is important to understand whether an individual has a number of risk factors present, which could mean the likelihood of injury or fatality was increased should a fire occur. With the community profiles Higgins et al,. (2013) were able to create a city map with heat zones which display the distribution of the community profiles. The research of Higgins et al. (2013), is similar to this study. The Higgins study is broader, since it involves all kind of criminal activities (like burglary) and accident risks.

Jennings (2013) used social and economic information from literature study to assess the risk of residential fire in urban neighbourhoods. Main goal of the research was to use this information to ensure better preventive activities by the government. The risk information has been combined with geographical data. Therefore it became possible to display the information in a geographical map. The research of Jennings (2013) gives an understanding of factors which are related to fire risk in neighbourhoods. Jennings (2013) views factors from different perspectives. However, these factors cannot be copied from this research, since there is a difference among factors between different countries and the Netherlands.

Trinh, Do, Wetz, & Anjomshoaa (2014) tried to develop a method to handle Linked Open Data in a dynamic way. The idea introduced, is to modularize functionalities into blocks. Users are able to combine linked open datasets to dynamically obtain, enrich, transform and visualize data in different ways. One of the research purposes is to study the flexibility in handling datasets during this research.

PROOF OF CONCEPT

Through interviews with several firefighters, it has become clear that in this area little research has been done ("We do not know a lot about which and how demographics affect fire risk, therefore we do not use it in the risk profiles we construct"). The safety region of Amsterdam-Amstelland has completed a statistical research on the relations between demographic factors and the risk of a dwelling fire. With this information, they could conduct precise communication with the appropriate target risk groups.

DWELLING FIRE RISK INDEX

The relations were extracted from "Handreiking social woningbrandrisicoprofiel". Some factors influence the risk positively and some negatively. The risks are based on demographics and involve risks like:

- Western immigrant resident – 15,7% lower risk.
- One parent family – 40% higher risk.
- Singe-person household – 11,5% higher risk.

Since the factors are not independent, it is not possible to do an independent probability calculation and therefore another method had to be used.

Dwelling Risk Index Calculation

All found data (proportions) were multiplied with the probability and added to each other. Therefore, it was possible to create an dwelling risk index for every neighbourhood. The proportion of the factor, times the probability gives a subscore. The subscores of all factors added up, give the risk index. For example, an area with 15% of "one parental families" (40% risk) results in the following sub score: $F_i*P_i = 15*0.40 = 6$. By linking the datasets, in accordance with the statistical relations and formula, the risk indexes have been calculated. Missing results have been filled out with the mean of the dataset. Computing this formula on the data has resulted in the left skewed distribution of risk indexes in Figure 2.

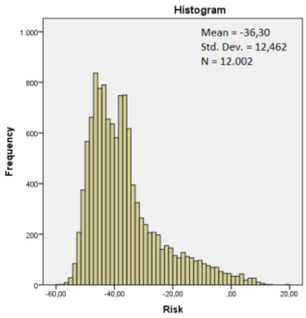

Figure 2. Distribution dwelling fire risks

NECESSARY DATASETS & DATASET APPROACH

Datasets were gathered from the internet. Extra datasets were gathered to create analysis beyond only the dwelling fire risk assessment, such as: response times and fire department locations. Spatial information was necessary to create geographic visualizations. The following datasets which are used in the Proof of Concept:

- Socio-Demographic datasets
- Spatial Data
- Response times and locations of the fire department
- Cadastral and address information

PROOF OF CONCEPT SCENARIOS

Putting all datasets together with the help of C#.NET and the Dotspatial library, has resulted in the Proof of Concept. The Proof of Concept calculates a risk index for all neighbourhoods in the Netherlands and gives a colour to the neighbourhoods corresponding to the risk index.

The Proof of Concept is able to provide insight into three different scenarios. In the future the Proof of Concept should provide more scenarios, or should be able to provide flexible scenarios. In the proof of concept the following scenarios are applied:

- Dwelling fire risks
- Urbanity versus fire department response
- Dwelling fire risk versus fire department response time.

Dwelling fire risk scenario

To determine whether a risk index is high or low, statistical percentiles have been used. The percentiles (and corresponding colours) have been used to determine the ratio in high or low areas. Risk indexes within the lowest percentile (10^{th} percentile) correspond with the lightest green, the highest percentile (100^{th}) corresponds with the darkest red. Figure 3 shows the result of this calculation, important to notice is that the more urbanized parts are the city parts with the highest dwelling risks, although population sizes were not used in the calculation.

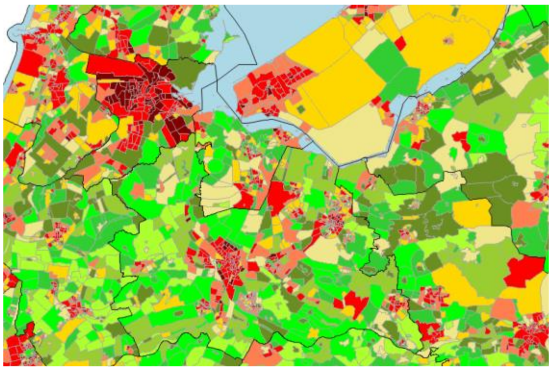

Figure 3. Dwelling fire risk Utrecht (Amsterdam red spot left).

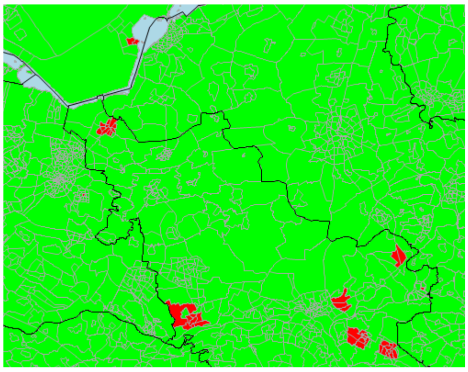

Figure 4. Urbanity vs. Response time Gelderland

Urbanity versus fire department response time scenario

Within the demographic data an attribute which represents the urbanity of the neighbourhood is present. A number between one and five is given. One is very strong urbanity and five is very weak urbanity. From moderate urbanity to very strong urbanity is used in this scenario. The maximum response time for structures with a residence function is 8 minutes. It might be interesting to know, in which regions the urbanity is moderate, strong or very strong with a response time beyond 8 minutes. Several neighbourhoods came up with this scenario. The red areas in Figure 7, have a moderate or strong urbanity (1000 up to 2500 addresses per km2) and the response time of the fire department is over 8 minutes.

Dwelling fire risk index, versus Fire Department Response Time scenario

The risk index could be used for more scenarios beyond the risk index itself. In the third scenario, the dwelling fire risk index has been combined with the fire department response time. Neighbourhoods with a high dwelling fire risk index are reflected in the response time of the fire department. Therefore, the risk indexes from the 90th percentile are shown in red in Figure 5 (high dwelling fire risk) when the response time is beyond the 8 minutes statutory maximum time.

Both scenario`s (Figure 6 & Figure 5) show almost the same areas in red. This is mainly caused by the fire department response time. The areas shown in red in both views are problem areas, because in these areas urbanity is strong, fire risk is high and response time is beyond 8 minutes statutory maximum response time.

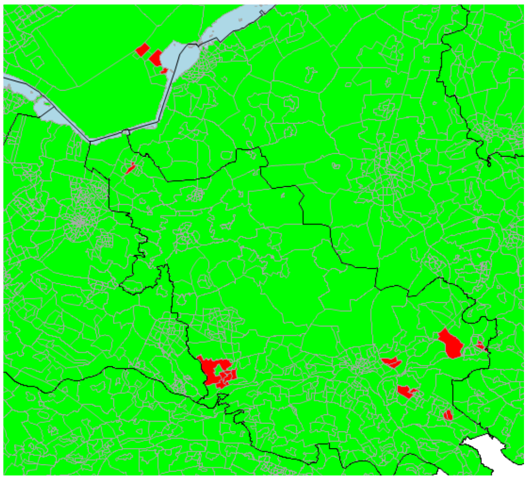

Figure 7. Risk index versus Response time Gelderland-Midden

PROOF OF CONCEPT EVALUATION

The statistical relations used have not been validated. The most important question is: ‘How do the outcomes of the Proof of Concept compare with reality?’.

Gut Feel Domain Expert

The three views made with the Proof of Concept have been verified. In these sessions has been shown that the dwelling fire risk index is the most valuable view, since the response time is needed for the other views and these response times are only available on municipality level. In this dataset the median of the response times per municipality has been taken as the mean. Therefore the results are not satisfactory altogether since the interesting results lie in the deviation of response time within a municipality. With a high probability the fire department could tell that the results of the two other views deviate from the reality.

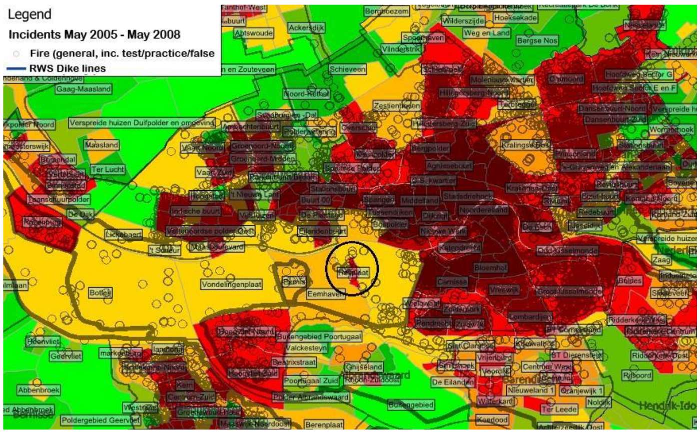

Figure 6. Overlay of fire incidents over dwelling fire risk indexes (Rotterdam-Rijmond.) “Heijplaat” is black circled.

Fire Risk Index

The verification of the dwelling risk indexes are based on the gut feelings of the fire department in their own region. The fire department has compared the outcomes from the Proof of Concept of their own region with the gut feelings of the fire risks in their own region. From this evaluation it turned out that there were similarities between the gut feelings of the fire department and the Proof of Concept: "*It seems to fit well*". The main statement is: “The risk indexes seem to fit well in general, probably there are some errors and deviations”. Although as a test during the evaluation a small high risk area “Heijplaat” (Figure 6) was taken which has a high risk, but from their gut feelings the firefighters disagree with this high risk. According to the firefighters this area should have a lower risk.

Fire Incident Map

The Fire Department of Rotterdam-Rijmond compared the outcomes with the incidents from 2005-2008 plotted on a map during evaluation. In Figure 6 the incident map is placed over the outcomes from the Proof of Concept. The high risk neighbourhoods had more fire incidents in the past than the low risk neighbourhoods. This overlay gives a better comparable view.

All participants in the evaluation agreed, that the Proof of Concept provides a good fire risk index. This conclusion has purely been drawn based on the comparison between the incident map and the fire risk map from the Proof of Concept tool. Moreover, “Heijplaat”, the area from the gut feeling evaluation part, appears to have had more fire incidents in the past than the average low risk areas. The high risk assigned to “Heijplaat” appears to be connected to reality.

Time needed to add a dataset

Because flexibility and dynamics are part of this study, the time needed to add the datasets was recorded. In this way an overview with the periods of time could be made. Important to note is that two periods (outliers) have a larger duration due to a learning curve needed to use the datasets.

Dataset	Time
Socio-Demographic data	3 Hours
Spatial data neighbourhoods	2 Hours
One parent family	2 Hours
Measured Response Time, Fire department	2 Hours
Locations of all fire departments in the Netherlands	15 Hours
Spatial data Safety regions	2 Hours
Construction years	12 Hours

Table 1. Time needed to add a dataset to the Proof of Concept.

In these results the “Locations of the fire departments” took 15 hours, due to the use of a different coordinate system. It took some time to find out how to align the different coordinate systems. The “constructions years” took more time as well. The dataset with the construction years is approachable with SPARQL. In this 12 hours the time learning about SPARQL is included.

Dynamics of datasets

The dynamics of a dataset are determined by the way of the dataset is provided and how easy it is to add the dataset to the Proof of Concept.

Only one dataset is provided in a dynamic way, which means that the dataset could be requested any time, any place (and monthly updated without the effort of downloading and updating the dataset locally). The other datasets (which are updated regularly) provide some form of dynamics as well, but since individual files should be downloaded from different sources on the Internet the dynamics are affected negatively. Which means these datasets should be managed by the Proof of Concept instead of requested and calculated from the source.

Dataset alignment

The identified datasets were from various sources. However the initial goal of the research was to use rather Linked Data (RDF) datasets, most datasets are in non-linked formats. Aligning(linking) the used datasets has been done upfront. Therefore administrative links were used which are already present in the datasets. Aligning has been done based on national determined neighbourhood codes and by following administrative links to other granularity levels (neighbourhood to postal code or even municipality level). The cadastral data provided as linked data was aligned on a similar way. After harvesting the data via their SPARQL endpoint, the resulting data was stored with the resulting data from the alignment process. Only one dataset was provided as pure Linked Data and therefore the power of “getting data directly from the source and link it” was not possible.

DATA EVALUATION

Quality dimensions

All data could be assessed on data quality. The quality is important to know, since the quality of the resulting information is determined by the quality of data.

Table 2. Quality dimensions. The not shown datasets are 100% on all dimensions.

Dataset	Extensional completeness	Intensional completeness	Consistency	Conciseness
Socio-Demographic data	100%	90.09% - Western foreign resident 90.09% - Dutch resident 93.45% - More residents on one address 93.45% - Single-person households 90.09% - 0-14 age in household 90.09% - 15-24 age in household 90.09%- Main tenant is 65 or older 89.05% - Sale houses 76.56% - Single storey apartment *100%* - Neighbourhood name *100%* - Municipality name *99.15%* - Population	100%	100%
Construction years (BAG)	76.63%	100%	100%	100%

As discussed under chapter Data Quality, completeness has been measured on the intensional and extensional level. Extensional completeness is about whether a dataset contains all objects from the real world (contains the dataset with buildings all buildings from the real world). Extensional completeness is represented in the second column of table 2. Intensional completeness is about whether a dataset contains all used or necessary attributes from the real world (contains the dataset with buildings a construction year, location and coordinates for each building). Intensional completeness is represented in the third column of table 2.

Furthermore, the accuracy levels of the datasets are different. The following datasets provide data on neighbourhood level:

- Socio-Demographic data
- Spatial data neighbourhoods
- Construction years (BAG)

The following datasets, provide data on municipality level:

- One parent family
- Measured Response Time

Error of data

According to the domain experts, the data present in the municipal databases are regularly incorrect. The demographic data used in this research are gathered by the CBS from the municipal databases (Basisregister Personen - BRP). The government conducted 5.000 home visits to research the correctness of BRP in 2014. Their conclusion: "*During the house visits it appeared in almost one third of the cases that there is indeed a difference between the registered persons and the people who actually live there*" (Rijksdienst voor Identiteitsgegevens, 2015). Therefore, there is a certain level of incorrectness in the data.

Completeness

The completeness of datasets is extensional almost 100% complete. The extensional completeness of BAG is not 100%. According to various sources (including the BAG itself) there are no exact numbers public about the completeness and the consistency of the BAG.

The intensional completeness of five datasets is 100%. The intensional completeness of the dataset with the demographic data of all neighbourhoods and the BAG are not 100%. This is not a problem, since the mean of the intensional completeness of both datasets is about 90%. Although, the missing data have been filled out with the mean, it will always cause errors in the information. In the outcomes, this means that no correct risk calculation can be done for areas with missing data on multiple factors.

Trust

All datasets in the proof of concepts are from government organizations. These organizations have a certain authority, the cadastral institution is responsible for publishing information on buildings and addresses (which are gathered from municipalities). Other datasets are published from the Dutch Health Organization and directly from municipalities. All datasets provide some form of meta-information (provenance). Which means that all datasets mention the creator and creation date, but none of them describes the creation method. The cadastre, does not describe a certain creation date but records a mutation table. Moreover, the cadastre does not record the creator of the data.

However trust is hard to measure, the trust of the used datasets is high. All data is retrieved from authorities and have limited meta-information.

Accuracy

Almost all datasets are on neighbourhood level. Since most datasets do not provide details about individual people, it is not possible to obtain a narrower level (house level e.g.) due to privacy restrictions. Several datasets are on municipality level. During the evaluation sessions the accuracy of the response times was a topic of discussion. The response time is now an average of the response times for a municipality, while it is interesting how this response time fluctuates among the neighbourhoods within a municipality.

The statistical relations used for the Proof of Concept, are about main tenants. The available demographic data contain the proportions of the characteristics in a neighbourhood and do not contain only the proportions of main tenants of the characteristics.

Furthermore, two factors on the age of children (0-11 and 12-17) are not equal to the factors in the data. The demographic data on children is from 0-15 and 15-25. It is unclear how these accuracy problems influence the quality of the outcomes. Probably the proportions of main tenants and the general proportions relatively relate to each other.

DISCUSSION

Necessary data

All necessary datasets were found to conduct a proper risk calculation. However, the statistical relations from the dwelling fire risk profile (“Handreiking sociaal woningbrandrisicoprofiel”) are not validated by other research nor further investigated. Therefore, the statistical relations are not complete (probably there are more factors) and there is no confirmation on the correctness of these factors.

Since the “Handreiking sociaal woningbrandrisicoprofiel” is the only statistical knowledge that is available, no other options were available to use for this research. Improvement of statistical knowledge and improvement of the factors will probably improve the dwelling fire risk calculation in the future.

Individual files

The main idea of this study is to create information by combining open datasets. All datasets used in the Proof of Concept are open datasets available on the internet. Compared to a business intelligence approach in which data warehouses are used, a linked open data approach keeps the data on the side of the provider. In practice it appears that almost all datasets are provided as a spreadsheet file which has to be downloaded from the internet instead of using a SPARQL interface to gather data from the provider. In the Proof of Concept only the data about construction years from BAG were provided through a SPARQL interface. Individual (spreadsheet) files means downloading and storing data yourself, in other words creating a data warehouse. Due to these static datasets, data alignment is harder, since static files contain different file formats which are stored locally. In a dynamic way (i.e. SPARQL) the output will be linked and combined with each other on the spot.

Outdated data

Four out of seven datasets used in the Proof of Concept are from 2013 or older. Important to note is that the dataset which contains the demographic data and the spatial data of all neighbourhoods in the Netherlands date from 2013. During the evaluation sessions the outdated data were discussed. During both sessions the fire department participants stated independently that demographic characteristics do not change in a few years. The outdated demographic dataset would not be a problem. However, the government sometimes invests a lot of money in a neighbourhood which could change the demographic characteristics of a neighbourhood. During the evaluation sessions the participants mentioned that the number of times such investments happen are negligible. The demographic dataset is always one to two years outdated and therefore the obsolescence of this dataset will not cause problems.

Dynamics of datasets

The dynamics of the Proof of Concept would be better, when all data could be requested as linked data, calculated and presented the outcomes, instead of downloaded, managed, calculated and presented the outcomes (which is currently the case).

Proof of Concept Architecture

During the development of the Proof of Concept, all data were added to the main dataset, which is the demographic dataset. In the end this turned out to be a wrong way of handling data, since most datasets are individual files. Updating data is not easy since all data are combined in one file. A better way to manage data, is to keep the datasets separate and link datasets together on data level. Because of this the management of data would be a lot easier.

One of the ways to do this, is to create a SPARQL endpoint for all datasets separately. The datasets could be linked to each other on the spot in the Proof of Concept. Because datasets stay separate, they could easily be updated (which is certainly not the case now). Moreover, adding new datasets would be easier when new datasets could be handled exactly the same way as all other datasets whatever data format they have. Therefore, dynamics and flexibility will be improved by using such an architecture.

CONCLUSION

The necessary datasets to conduct a dwelling fire risk index were found, in some cases the accuracy is a problem. Furthermore, there is a slight accuracy mismatch in the demographic dataset. Also, the meta-information is too limited. From most datasets only the creator and creation date are available. All datasets are provided by authorities which affects the trust positively in the data quality. Most datasets are 2 years old, this is not necessarily a problem. During the research the purpose was to create a risk profile based on particularly demographics. Demographics of a neighbourhood do not change very often. Demographics tend to stay the same over a longer period. However there are exceptions, after a restructuring or neighbourhood renovation demographics can change drastically due to an significant attraction of people with other demographic characteristics.

Based on gut feeling all domain experts could verify that the results seemed to be right on the first impression. The comparison of the outcomes with the fire incidents in the past plotted on a map from the fire department, was surprisingly similar. The fire incident map and the outcomes of the Proof of Concept have been compared successfully by a domain expert as well. With the used datasets and the used statistical relations, it seemed to be possible to do a successful dwelling fire risk assessment. The dynamics of the Proof of Concept was not as expected. Since almost all datasets are provided as individual files and had to be converted to linked data ourselves before we could easily combine, match and calculate data. The evaluation sessions with the domain experts have given an indication of the correctness of the outcomes. However, it would be a good thing to find more ways to verify the outcomes.

ACKNOWLEDGMENTS

I would like to acknowledge those who have helped to achieve the goals of this study. I would like to thank Jan Wielemaker (VU University Amsterdam) for his guidance and support throughout the research. I would like to thank Bart van Leeuwen as well. Bart fulfil the role as domain expert, Bart has helped with his firefight and Linked Open data expertise. I would like to thank the domain experts of the fire department Netherlands which have contributed to this research during the evaluation sessions. Without their help it would be impossible to learn about the correctness of the outcomes.

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Research on the forecasting of Air Quality Index (AQI) based on FS-GA-BPNN: A case study of Beijing, China

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ABSTRACT

The analysis and forecasting of eminent air quality play a significant role in municipal regulatory planning and emergency preparedness. In this paper, a FS-GA-BPNN model forecasting the daily average Air Quality Index (AQI) is proposed. Special procedures for feature extraction to find more potential significant variables and feature selection to remove redundant information and avoid overfitting are conducted before modelling. Three different models – BPNN, GA-BPNN and FS-GA-BPNN are established to compare the prediction accuracy, generalization ability and reliability. 17 parameters involving pollutant concentration, meteorological elements and surrounding factors are found essential for the method effectiveness. The result shows that the FS-GA-BPNN model generally performs superior to ordinary BPNN, suggesting the necessity of extensive data mining and feature extraction for successful machine learning. The results of this paper can help to conduct air quality pre-warning system and improve the emergency planning process of extreme weather events.

Keywords

Feature Selection, Genetic Algorithm, Backpropagation Neural Network, Air Quality Index, forecasting

ABBREVIATIONS

ANN	Artificial Neural Network
AP1	AQI Value Of The Next Day
AQI	Air Quality Index
BPNN	Back Propagation Neural Network
FS	Feature Selection
GA	Genetic Algorithm
MAE	Mean Absolute Error
MSE	Mean Squared Error
OLS	Ordinary Least Squares
R	Pearson Correlation Coefficient
RMSE	Root Mean Squared Error
SVR	Support Vector Regression
WNN	Wavelet Neural Network

INTRODUCTION

There is robust scientific evidence confirming that the air pollution has been the largest single environmental risk and a leading cause of physiological diseases and respiratory mortality globally (Fischer et al., 2011; Mahiyuddin et al., 2013). Chinese cities experience particular high airborne particle concentrations. According to the latest China Environment Status Bulletin 2015, the ambient air quality of 265 cities exceed the national standard, accounting for 78.4% of the total 338 monitored cities, and typical annual maximal daily average $PM_{2.5}$ concentration was reported to be as high as 477.5 μg/m^3 in Beijing. To avoid these extreme weather events, a reliable forecasting technique is needed which plays an important role in the crisis response and emergency planning.

Existing air quality forecasting techniques and tools can be grouped into three categories (Hajek and Olej, 2015): simple empirical approaches, physically-based approaches and statistical approaches. The simple empirical approaches are usually too delicate to handle abrupt changes of weather, emissions and air quality (U.S. EPA, 2003). The physically-based forecasting systems generally demand sound knowledge of the pollution sources and are sensitive to the initial and boundary conditions. Besides, they require the assist of equipment with high performance computing capacity and weather forecast model with high spatio-temporal resolution (Zhang et al., 2012). The statistical approaches are usually confined to the area and conditions present during the measurements and lack a better understanding of the chemical and physical evolution processes. So the growing trend is to combine the physically-based models with statistical ones to provide more accurate prediction.

Since the first application for ambient pollutant concentrations modeling by Boznar et al. in 1993, ANN has been recognized as a cost-effective method for this task, superior to traditional statistical techniques and gained widely extension in this field (Challoner et al., 2015). However most of the inputs variables of established ANN models were based on experience, common sense or subjective inference from the existing scientific literature (Fu et al., 2015; Perez and Salini, 2008). Some researchers attempted to process feature selection before the training of artificial neural network. Grivas et al. (2006) applied a genetic algorithm optimization procedure for the selection of the input variables and compared the prediction results with multiple linear regression models. Mesin et al. (2010) introduced partial mutual information criterion to select the predictors and utilized Hampel test criterion to assess the significance of selected variables for the system output. Qin et al. (2014) conducted Gray Correlation Analysis (GCA) to search possible predictors for developed CS-EEMD-BPANN model to forecast following hourly particulate matter concentrations. But the interpretability and multicollinearity of most feature selection results still remain ambiguous and controversial.

This study introduces regularization-based feature selection for the filtering of model inputs to eliminate redundant information, alleviate multicollinearity and enhance generalization ability. Two ordinary BPNNs, an evolutionary model optimized by GA and a hybrid model with feature selection are established as contrast, respectively. Statistical indices like Pearson correlation coefficient (R), root mean square error (RMSE) and mean absolute error (MAE) are used to evaluate the reliability of different models.

STUDY AREA AND THE DATA

Study area

This study focuses on the area of Beijing municipality and surrounding cities including Baoding, Chengde, Tianjin, Zhangjiakou and Langfang whose suspended particulate matters and air pollutants can easily affect the air quality of Beijing (Figure 1).

Since 2012 an air pollution monitoring network including 35 monitors has been constructed gradually by Beijing Municipal Environment Monitoring Center. Among the 35 monitoring stations, 17 are located in the urban districts and 18 in suburban districts (Figure 1). The monitoring objects include major air pollutants and meteorological factors according to the new regulation issued by the Ministry of Environmental Protection of China (MEP).

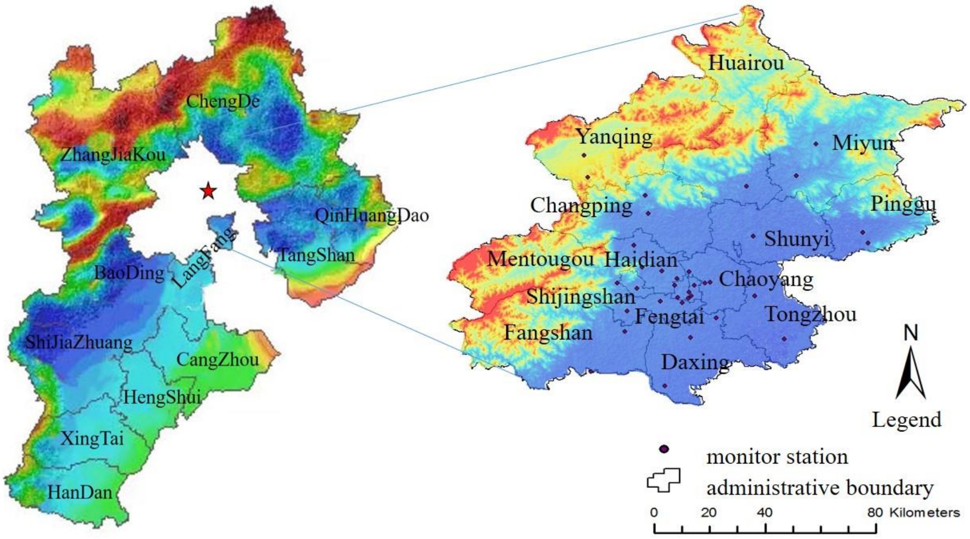

Figure 1. The surrounding cities and administrative division of Beijing municipality, with the monitoring stations labeled on the right part.

Data collection and pre-processing

The Air Quality Index proposed in the new regulation is defined as a function of several sub-indicators shown in Eq.(1) and Eq.(2), involving such pollutants as $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3, which are classified by the mass concentration respectively (HJ 633-2012). So it is imperative to list pollutants, meteorological data and surrounding factors as alternate variables for neural network inputs.

$$AQI = max\{IAQI_1, IAQI_2, IAQI_3, \dots IAQI_n\} \tag{1}$$

$$IAQI_n = \frac{IAQI_{Hf} - IAQI_{Lo}}{BP_{Hf} - BP_{Lo}} (C_n - BP_{Lo}) + IAQI_{Lo} \tag{2}$$

In Eq.(1) and Eq.(2), the $IAQI_n$, $IAQI_{Hf}$, $IAQI_{Lo}$ refers to the corresponding sub-indicators of AQI respectively. The C_n refers to the mass concentration of pollutant n. BP_{Hf} and BP_{Lo} refers to the high-value and low-value of pollutant concentration n.

The analysis is based on historical daily averaged data from 1st February, 2013 to 31st July, 2016, spanning a total of 1277 days. Descriptive statistics for AQI and Particulate Matters during the observed period are presented in Table 1. Ground measured hourly pollute concentration data including PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3 and AQI are collected from the Beijing Municipal Environment Monitoring Center (http://zx.bjmemc.com.cn/) and then calculated as daily mean values. The meteorological data including Barometric pressure, Air temperature, Relative humidity, Wind direction, Wind velocity, Precipitation and Duration of sunshine are acquired from National Meteorological Information Center (http://data.cma.cn/). The AQI values of surrounding 5 cities are obtained from the data center of MEP (http://www.mep.gov.cn/).

Table 1. Basic descriptive statistical characteristics for the main indicators

Statistical Characteristics	AQI	$PM_{2.5}$	PM_{10}
Arithmetic mean	113.4	80.1	106.1
Median	92.0	61.0	90.6
Standard Deviation	74.6	66.8	72.0
Range	15 - 475	5.2 – 477.5	1.8 – 480.8

All values in μg/m^3 except Standard Deviation and AQI (dimensionless).

Apart from the basic quality control (e.g. excluding missing data) of row data, additional attention is paid to feature extraction to integrate both quantitative and qualitative data and discover more potential input variables.

The AQI of the next day (AP1) is illustrated as a response of wind direction of the previous day (Figure 2). And the wind direction (in degree) are transformed to sine and cosine variables to help interpret the periodicity of prevailing wind. Besides, according to the wind roses, an additional variable is defined to fit the corresponding relationship between wind direction and AP1 as follow:

$$\mathrm{WD} = \left|\sin\left(\theta + \frac{4}{3}\pi\right)\right| \quad (3)$$

where θ refers to the wind direction (in radians), and the $4/3\pi$ represents the additional bias which makes the WD reach maximum when θ obtains the prevailing direction (i.e. south west and north east) and zero when the direction is south east or north west.

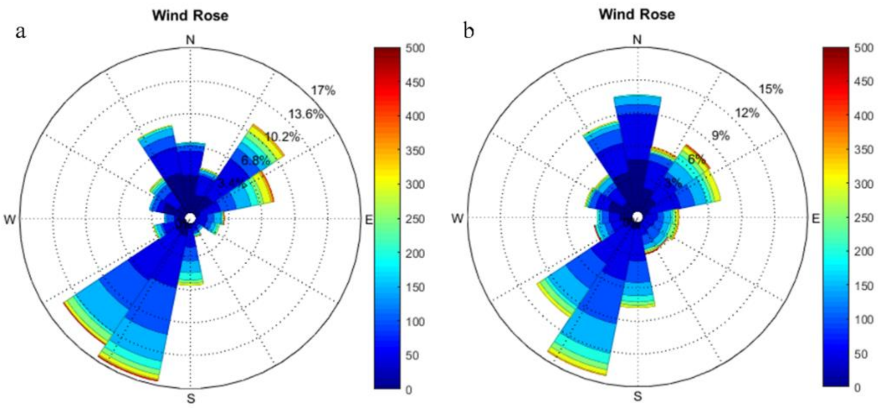

Figure 2. a. Wind Rose for direction of maximum wind speed VS AQI; b. Wind Rose for direction of extreme wind speed VS AQI. The radius refers to the frequency of specific wind direction and the intensity of color refers to the value of AQI.

To incorporate the effect of the weekly variation of pollutants emission, another index is introduced by adding a weight to every week day expressed as Eq.(4). The $\overline{x_i}$ refers to the mean AQI of specific day in a week and $\bar{x}$ represents the mean value of the whole year.

$$\mathrm{DoW} = \frac{\overline{x_i}}{\bar{x}} \times 100\% \quad (4)$$

$$\{i = \ Monday, Tuesday - Friday, Saturday, Sunday \ and \ other \ official \ hoidays\}$$

The effect of precipitation is also considered as a binary variable (0/1) represented by Pre_b. And based on the statistical analysis of the row data, the seasonal effect is taken into account as illustrated in Eq.(5). The $\overline{x_i}$ refers

Table.2. Definitions of raw data parameters

Parameter	Abbreviation	Unit	Description
Index	AQI		Air quality index of Beijing
	Dow		The effect of the weekly variation
	SE		Seasonal effect
	SCI		Shanghai Composite Index
Pollutants	$PM_{2.5}$	μg/m^3	Daily averaged concentration of $PM_{2.5}$
	PM_{10}	μg/m^3	Daily averaged concentration of PM_{10}
	SO_2	μg/m^3	Daily averaged concentration of SO_2
	CO	mg/m^3	Daily averaged concentration of CO
	NO_2	μg/m^3	Daily averaged concentration of NO_2
	O_3	μg/m^3	Daily averaged concentration of O_3
Meteorological Factors	P_mean	0.1hPa	Mean barometric pressure
	P_max	0.1hPa	Maximum barometric pressure
	P_min	0.1hPa	Minimum barometric pressure
	▵P	0.1hPa	Daily maximum pressure difference
	T_mean	0.1℃	Mean air temperature
	T_max	0.1℃	Maximum air temperature
	T_min	0.1℃	Minimum air temperature
	▵T	0.1℃	Daily maximum temperature difference
	Vap	0.1hPa	Average vapor pressure
	Eva_s	0.1mm	Small evaporation
	Eva_l	0.1mm	Large evaporation
	H_mean	1%	Mean relative humidity
	H_min	1%	Minimum relative humidity
	Pre	0.1mm	Precipitation
	Pre_b	binary	Precipitation in binary code
	v_mean	0.1m/s	Mean wind velocity
	v_max	0.1m/s	Maximum wind velocity
	v_max_n	1-16	Maximum wind velocity direction in number
	v_max_d	degree	Maximum wind velocity direction in degree
	Sin_max		Sine of maximum wind velocity direction
	Cos_max		Cosine of maximum wind velocity direction
	Sin(x+4/3π)_max		Transferred maximum wind velocity direction
	v_ext	0.1m/s	Extreme wind velocity
	v_ext_n	1-16	Extreme wind velocity direction in number
	v_ext_d	degree	Extreme wind velocity direction in degree
	Sin_ext		Sine of extreme wind velocity direction
	Cos_ext		Cos of extreme wind velocity direction
	Sin(x+4/3π)_ext		Transferred extreme wind velocity direction
	Sun	0.1hour	Duration of sunshine

Table 2. Definitions of raw data parameters

Parameter		Unit	Description
Background factors	BD		Air quality index (AQI) of Baoding
	CD		Air quality index (AQI) of Chengde
	LF		Air quality index of (AQI) Langfang
	TJ		Air quality index of (AQI) Tianjin
	ZJK		Air quality index of (AQI) Zhangjiakou

to the mean AQI of specific season and $\bar{x}$ represents the mean value of the whole year, with *i* ranging from spring to winter.

$$\mathrm{SE} = \frac{\overline{x_i}}{\bar{x}} \times 100\% \qquad \{i = Spring, Summer, Autumn, Winter\} \tag{5}$$

To implement the estimation of the emission intensity of pollution source and the economical background conditions, the daily volume of Shanghai Composite Index (reflecting the daily variability in the trading of main listed shares in China, abbreviated as SCI) is taken as a supplementary variable. The total variable considered in this paper is listed in Table 2.

Besides, all of the raw data are normalized to fall in the range of [−1, 1] via the following formula:

$$y = \frac{(x - x_{min})}{(x_{max} - x_{min})} * (y_{max} - y_{min}) + y_{min} \tag{6}$$

where x is the element of each observation vectors, y is the normalized value at observation i, x_{min} and x_{max} are the minimum and maximum of each observation vectors respectively, and y_{min} , y_{max} are the minimum and maximum of each normalized vectors (-1/1).

METHODOLOGY

Back propagation neural network

Back Propagation Neural Network (BPNN), a multilayer feed forward neural network trained by error back propagation algorithm to minimize the sum squared error of network is adopted in this paper, with the learning algorithm ranging from Levenberg-Marquardt backpropagation to Bayesian Regularization backpropagation and Scaled Conjugate Gradient backpropagation, seeking for the best performance of networks. It has been proved that a single hidden layer network can approximate any continuous function to any desired accuracy, given sufficient neurons in the hidden layer (Guliyev et al., 2016). A typical neural network architecture is briefly illustrated in Figure 3. Each input is weighted with an appropriate weight W and the sum of the weighted inputs and bias ($IW+b^1$) forms the input to the hidden layer transfer function f_H. The output layer works similarly with the hidden layer with few differences on the transfer function f_O to generate their output. The structures adopted in this paper are all based on this architecture with the specific input preprocessing method, neuron count and optimization algorithm vary and complicate for different models. The early-stopping technique and regularization method are applied respectively as contrast to avoid overfitting. For each method, the original data are divided into two subsets evenly with one set reserved as training set (85%) and the other cross validation set (15%).

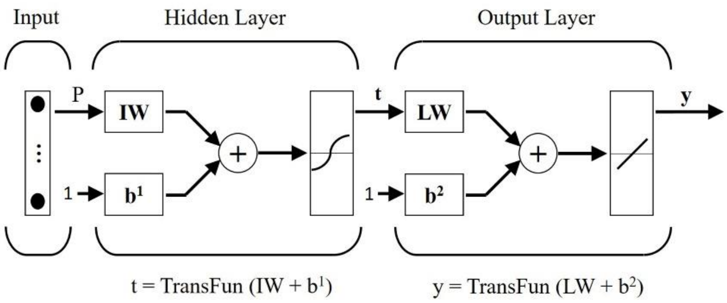

Figure 3. Typical structure of neural networks.

Regularization-based feature selection

In supervised machine learning settings with many input variables, overfitting is usually a potential problem unless there is ample training data (Srivastava et al., 2014). Efficient and robust feature selection methods are usually needed to extract meaningful features and eliminate noisy ones. In this paper, two standard regularization methods – the L_1 regularization, which uses a penalty term to force the sum of the absolute values of the parameters to be small, and L_2 regularization, which minimizes the sum of the squares of the parameters - are applied to identify important predictors, reduce input dimension and enhance the generalization ability.

Lasso regression

Lasso (least absolute shrinkage and selection operator), a regression analysis method that performs both variable selection and regularization, was originally formulated for ordinary least squares models (OLS) and then extended to a wide variety of statistical models. Different with OLS, it adds a positive penalty term (L_1 norm of coefficient vector) to the error function that forces the estimated coefficients of minority features to be zero (Tibshirani, 1996). The sparse parameter vector makes it a natural candidate for feature selection, and meanwhile, can present smaller mean squared error than an OLS estimator when applied to new data. The objective of Lasso can be written compactly as

$$min_{\beta_0,\beta}\left\{\frac{1}{N}\sum_{i=1}^{N}(y_i-\beta_0-x_i^T\beta)^2+\lambda\sum_{J=1}^{P}\left|\beta_j\right|\right\} \tag{7}$$

where N is the number of observations, each of which consists of p covariates and a single outcome. x_i and y_i are the values and response at observation *i*. λ is a positive regularization parameter.

Ridge regression

Ridge regression is the most popular method of regularization for ill-posed problems in statistics. Similar with Lasso, Ridge improves generalization ability by shrinking regression coefficients to avoid overfitting, but it does not set any of them to zero (Ng, A. Y., 2004). So it can be an implement for Lasso to avert the missing of important variables. The difference between Lasso and Ridge lies in that Ridge introduces L_2 norm of coefficient vector into the error function, which gains the Ridge more stable performance for coefficients estimation. The Ridge regression model can be interpreted as follow:

$$min_{\beta_0,\beta}\left\{\frac{1}{N}\sum_{i=1}^{N}(y_i-\beta_0-x_i^T\beta)^2+k\sum_{J=1}^{P}(\beta_j)^2\right\} \tag{8}$$

where the meanings of variables are the same as those in Lasso, except that the $||\beta||_1$ is replaced as $||\beta||_2$ and the k represent the Ridge parameter.

Genetic Algorithm

Genetic algorithm (GA) is a highly parallel, auto-adaptive computation metaheuristic inspired by the process of natural selection to search the global optimal solution by bio-inspired operation rules such as selection, crossover and mutation. The selection rules choose the parent individuals for the next generation based on their scaled values at the fitness function. The crossover rules combine two parents to form children for the next generation. The mutation rules implement random changes to parent individuals to form children with a fixed probability. The algorithm is frequently used for optimization of various established models (Gan et al., 2016; Wang et al., 2015).

In this paper, GA is implemented as an optimization for the weight and bias of ANN to avoid the local minimum and improve the prediction accuracy. The RMSE of the predicted daily mean AQI is taken as the fitness function of GA, and the schematic representation of the hybrid algorithm is shown in Figure 4.

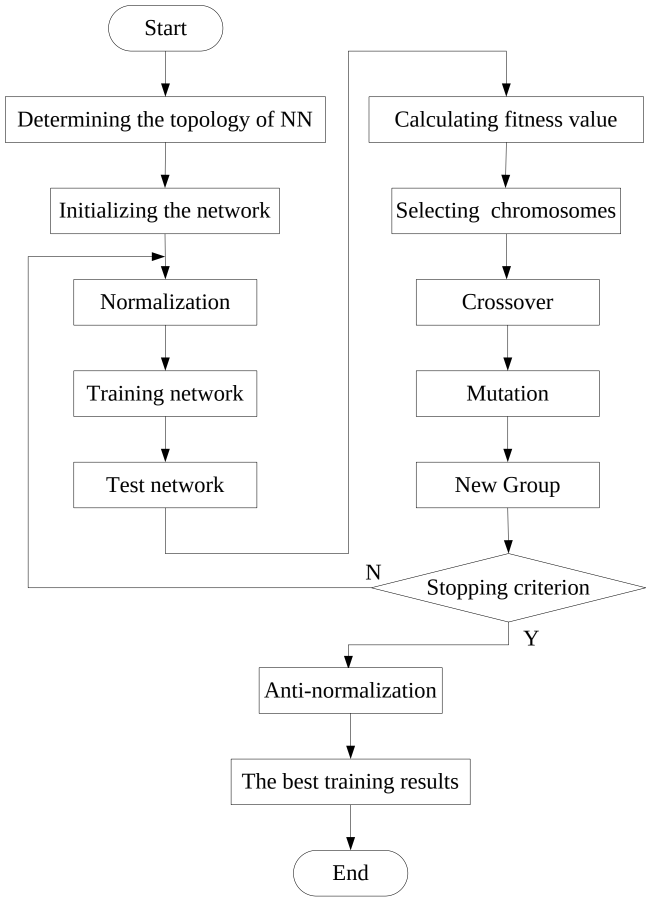

Figure 4. The algorithm flow of the optimized model. The left part of the diagram is the process of ANN while the right part the procedure of GA. Note that the input variables has been optimized by feature selection.

RESULTS AND DISCUSSION

Feature selection result

In this paper, a 10-fold cross validation is performed to estimate the MSE during the Lasso regularization, where the original sample is randomly partitioned into 10 subsamples, with one single subsample remained as validation set and the other 9 subsamples as training set. The optimal regularization parameter (λ) with minimal MSE plus one standard deviation is then used to calculate the coefficient of corresponding variables. The trace plot of coefficient fit and cross validation MSE are shown as Figure 5.

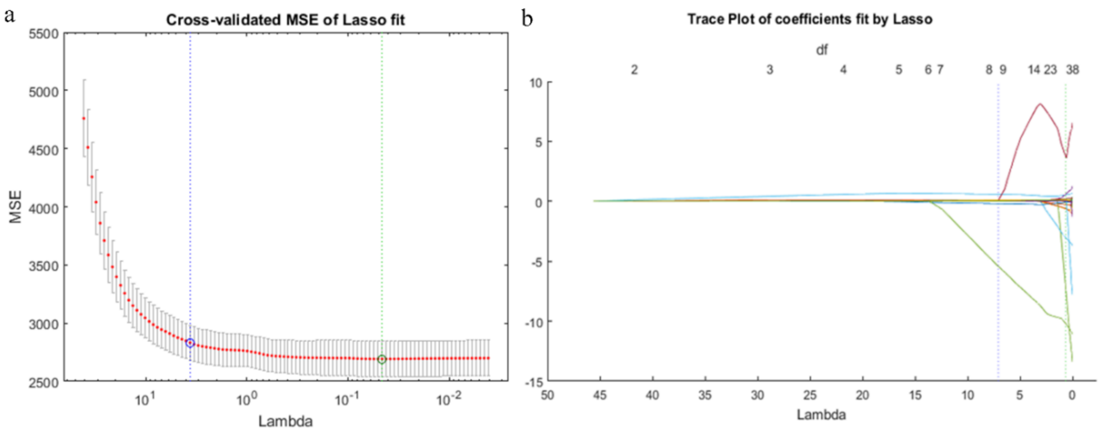

Figure 5. a. The cross validated MSE of Lasso fit. b. The trace plot of coefficient fit by Lasso.

The selection result of Lasso regularization is listed in Table 3, indicating that the most important variables for the prediction of AQI are cos_ext (negative correlation) and sin(x+4/3π)_max (positive correlation), followed by meteorological factors such as Pmin (positive correlation), Vext (negative correlation) and Sun (positive correlation) and main pollutant concentration such as $PM_{2.5}$, PM_{10} and NO_2.

Table.3. Coefficients estimated by Lasso

Factor	**AQI**	**$PM_{2.5}$**	**PM_{10}**	**NO_2**	**Pmin**	**sin(x+4/3π)_max**	
Coefficient	0.0826	0.0853	0.1116	0.517	0.0114	6.7743	
Factor	**Vext**	**cos_ext**	**Sun**	**LF**	**ZJK**	**BD**	**others**
Coefficient	-0.2419	-7.9065	0.0514	0.072	0.0765	0.0138	0

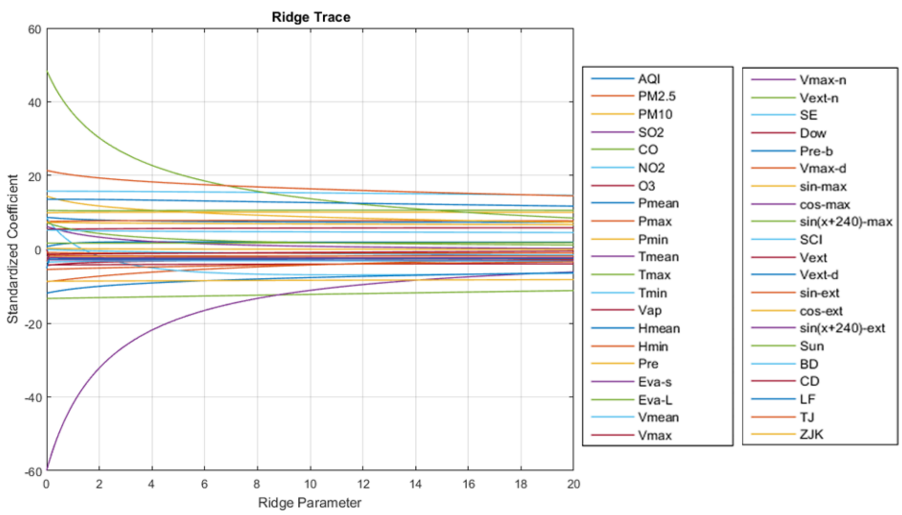

Figure 6. The trace plot of Ridge regression.

Table4. Coefficients estimated by Ridge

factor	AQI	Dow	SE	SCI	$PM_{2.5}$	PM_{10}
k=0	6.81	1.41	-1.84	0.99	9.30	9.00
k=20	7.08	1.49	-1.83	1.28	8.67	9.29
change /%	3.99%	5.67%	0.54%	29.29%	6.79%	3.26%
factor	SO_2	CO	NO_2	O_3	P_mean	P_max
k=0	-4.49	-14.94	21.39	7.00	-2.31	-8.25
k=20	-2.67	-12.04	18.02	7.12	1.52	-2.69
change /%	40.49%	19.40%	15.77%	1.72%	165.96%	67.33%
factor	P_min	Vap	T_mean	T_max	T_min	Eva_s
k=0	16.26	4.93	-65.01	40.53	0.77	-0.23
k=20	8.11	1.63	-10.24	3.96	-10.89	-0.24
change /%	50.11%	66.93%	84.25%	90.22%	1520.99%	4.34%
factor	Eva_l	H_mean	H_min	Pre	Pre_b	v_mean
k=0	17.59	-7.71	20.15	4.87	0.42	-1.26
k=20	13.03	-3.65	14.17	5.26	0.42	-2.49
change /%	25.95%	52.73%	29.69%	8.01%	0%	98.42%
factor	v_max	v_max_n	v_max_d	Sin_max	Cos_max	Sin(Φ)_max*
k=0	-6.82	0.00	-3.52	-1.14	-2.28	1.75
k=20	-5.64	-1.82	-1.82	-1.25	-2.50	1.87
change /%	17.34%	-	48.22%	9.81%	9.89%	7.03%
factor	v_ext	v_ext_n	v_ext_d	Sin_ext	Cos_ext	Sin(Φ)_ext*
k=0	-3.18	0.00	-5.19	-0.42	-9.07	-1.99
k=20	-3.85	-2.42	-2.42	-0.53	-8.59	-2.01
change /%	21.23%	-	53.48%	25.23%	5.35%	1.21%
factor	Sun	BD	CD	LF	TJ	ZJK
k=0	8.69	6.65	-1.42	13.63	-6.86	7.73
k=20	9.54	5.86	-0.71	11.71	-4.41	6.91
change /%	9.67%	11.89%	50.35%	14.10%	35.60%	10.65%

*$\Phi=x+4/3\pi$

The Ridge regression is performed with the parameter k ranging from 0 to 20 (Figure 6). With the increase of k, most of the coefficients decrease towards zero but the traces are apparently steadier than Lasso. Except the same variables selected by Lasso, CO, Hmin and Eva-L gains similar estimation as NO_2 in Ridge, which may be omitted by Lasso and need to be taken into consideration. Besides, the Tmean shows distinctive performance in Ridge, with the coefficient ranging from around -65 to -10 and the same as T_{min}, with the coefficient multiplying by more than15 times from 0.76 to 10.88. Part of coefficients estimated by Ridge are listed in Table 4.

Based on the analysis above, this study totally finds 17 significant variables for the prediction of AQI and takes them as the input of NN models – *AQI, $PM_{2.5}$, PM_{10}, NO_2, CO, Pmin, Hmin, Tmean, Tmin, Eva-L, sin(x+4/3π)_max, Vext, cos_ext, Sun, LF, ZJK and BD* (see Table 2 for complete definition).

Statistical studies using meteorological data and air pollution monitoring data have confirmed that the meteorological condition affects the dispersion, transformation and removal of pollutants in the atmosphere and finally influences the spatial-temporal distribution characteristics and air pollution levels in numerous ways (Tian et al., 2014; Yin et al., 2016; Zhang et al., 2015). The selection result in this study shows partial consistency with the previous researches, confirming the prominent relationship between air quality with main air pollutants and meteorological parameters. Besides, the contribution of such meteorological factors as daily minimum of relative humidity, barometric pressure and temperature (instead of the daily averaged values used in most relevant researches before) to the prediction of AQI is of notable significance but rarely reported. The air quality of surrounding cities also takes an indispensable role in the pollution level of observed subject, verifying the necessity of sufficient relevant variable mining. The selection of such variables as *cos_ext* and *sin(x+4/3π)_max* proves the validity of feature extraction in this research which are also rarely reported in previous work.

Comparative evaluation of the models

During the training process, the original data is divided into two subsets – one for supervised machine learning and the other for cross validation. Statistical indices like Pearson correlation coefficient (R), root mean square error (RMSE) and mean absolute error (MAE) are used to evaluate the reliability of different models. R is used to describe the degree the prediction approximating the observation. The model is more reliable when R is closer to one. RMSE and MAE are applied to quantify the forecasting errors which indicates a higher prediction accuracy when these indices are closer to zero. R, RMSE and MAE are calculated as follow:

- The correlation coefficient (R) of the observed and predicted data :

$$R = \frac{\sum_{i=1}^{n}(y_i-\bar{y})(\hat{y}_i-\bar{\hat{y}})}{\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}\sqrt{\sum_{i=1}^{n}((\hat{y}_i-\bar{\hat{y}})^2}} \tag{9}$$

- The root mean square error (RMSE) :

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i-\widehat{y_i})^2} \tag{10}$$

- The mean absolute error (MAE) :

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i-\widehat{y_i}| \tag{11}$$

In Eq. (9-11), n is the number of data point. $\widehat{y_i}$ is the predicted value. y_i is the real observed value. $\bar{\hat{y}}$ is the average predicted value and $\bar{y}$ is the average observed data.

Three different models are established to compare the reliability and prediction accuracy – BPNN, GA-BPNN and FS-GA-BPNN. GA-BPNN is the evolutional model of BPNN optimized by Genetic Algorithm, while the FS-GA-BPNN is the hybrid model of Feature Selection, Genetic Algorithm and Backpropagation Neural Network. In contrast of the old regulation, a BPNN model utilizing corresponding predictors included in the old national standard is constructed on parallel. The statistical indices for performance evaluation of these models are presented in Table5.

As is seen in Table 5, there are not tremendous performance gap between the training sets and test sets in all models, suggesting a reasonable structure of the inner architecture. The BPNN* performs slightly better than BPNN. This may be attributed to the redundant information contained in the input of the latter, which makes the neural network learn too many meaningless details and erodes the generalization ability. The GA-BPNN shows a better performance than BPNN and BPNN* but a little poor prediction accuracy, with the R of testing set reaches

Table.5.The prediction results of different models

Model	BPNN*	BPNN	GA-BPNN	FS-GA-BPNN
Structure	4-4-1	28-24-1	28-24-1	17-17-1
Training Set				
R	0.89	0.80	0.89	0.90
MAE(μg/m^3)	37.62	40.27	34.99	30.02
RMSE(μg/m^3)	51.64	53.23	47.23	27.11
Testing Set				
R	0.73	0.69	0.75	0.82
MAE(μg/m^3)	41.52	41.33	37.73	33.91
RMSE(μg/m^3)	54.78	57.37	51.55	40.26

The model BPNN* represents the neural network using observed data according to the old regulation as input.

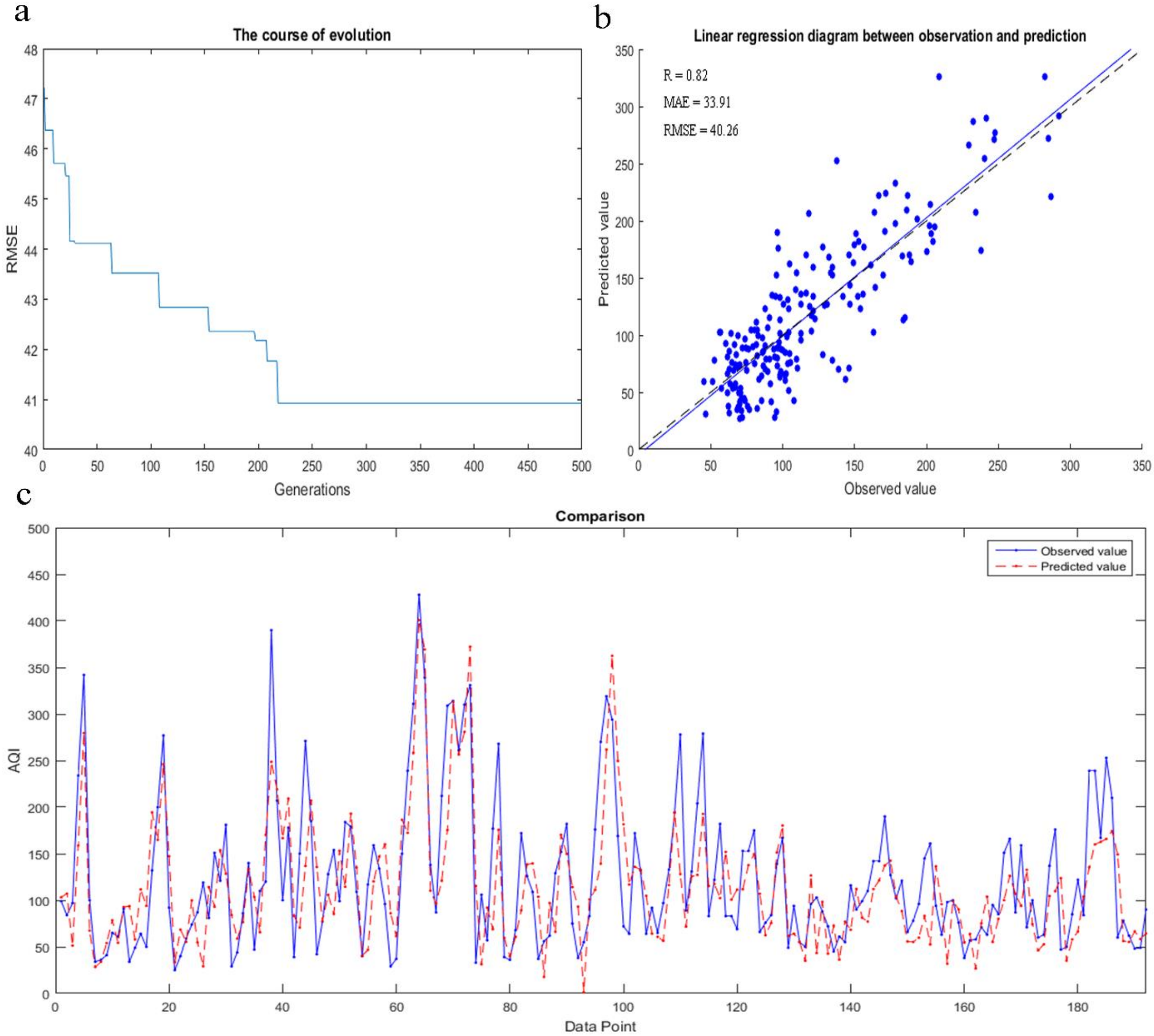

Figure 7. a. The GA optimization course, with the best RMSE=40.26 at generation 221; b. The regression line between the prediction and observation; c. Comparison of predicted value and observed value in testing set.

only 0.75 when the training set obtains 0.89. The GA still makes a remarkable contribution to the optimization of BPNN, minimizing the RMSE by around 10.14%. Both RMSE and MAE of FS-GA-BPNN model are lower than the other three models, and the correlation coefficient is the highest in all models, with the RMSE and MAE decreasing by 21.9% and 10.12% and R increasing by 9.33% compared with GA-BPNN, certifying the effectiveness of feature selection. The procedure of feature extraction and feature selection not only improves the generalization ability and reduce the complexity of NN models but also increases the prediction accuracy. The GA optimization course, regression line and the comparison between observed and predicted value in testing set of FS-GA-BPNN model are shown in Figure 7.

CONCLUSIONS

Driven by deteriorated air quality and increased societal demands, the emergency planning for extreme weather crises have raise extensive concerns from communities, organizations and government worldwide. Accurate air quality forecasting can be used to issue early air quality alerts that allow government and people to take precautionary measures such as temporarily shutting off major emission sources and avoid direct exposures to polluted outdoor environment. These actions can significantly alleviate the government pressure of municipal regulatory management and relieve the adverse health impacts on individuals, which therefore can bring tremendous societal and economic benefits in the long run.

In this study, a FS-GA-BPNN model forecasting the daily average Air Quality Index (AQI) based on Feature Selection (FS), Genetic Algorithm (GA) and Backpropagation Neural Network (BPNN) is proposed. Different from traditional practice of empirically choosing input for supervised machine learning, a special procedure for feature extraction to find more potential significant variables and feature selection to remove redundant information and avoid overfitting is conducted before training the neural network. Three different models are established to compare the prediction accuracy, generalization ability and reliability of different methods. The result shows that the FS-GA-BPNN generally performs 10% - 20% better than an ordinary BPNN and that optimized by Genetic Algorithm alone. The model can help to recognize the causes of weather crisis, improve the emergency preparedness and planning process and sequentially help to conduct air quality pre-warning system and enhance crisis management ability.

The training of the developed ANNs are based on the limited observation duration and restricted to the sampling location of Beijing. However, the benefit of ANN models can be improved by incorporating the following aspects in the future research: (1) Periodic expansion of training sets, exhaustive recognition and quantification on the pollution source and appropriate refinement for data preprocessing method (2) Comparison of other prevailing machine learning algorithms such as Support Vector Regression (SVR), Wavelet Neural Network (WNN) etc. ; (3) Investigation of the validity of ANN models for different cities around the country; (4) Exploration of the capability of ANN models in predicting AQI in two or three days advance.

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Towards Projected Impacts on Emergency Domains Through a Conceptual Framework

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ABSTRACT

In emergency domain, experts must make decisions both usual and unusual. These decisions lead to unpredictable impacts, causing the need for these experts to deal with impacts mitigation. Unexpected need of impacts mitigation consists in an overload of material resources and expert cognitive capacity. After decision making, impacts mitigation demands valuable expert efforts. To address this problem, this paper proposes a decision impact projection in early stages of emergency management, during planning stage. In this way, this paper proposes the method called General Conceptual Framework (GCF) and the Framework of Projected Impact on Emergency Domain (PIED). Through the proposed method, PIED Framework was developed, contributing for the characterization of impact projection in emergency environments.

Keywords

Projected Impacts, Emergency, Complex decisions, Conceptual Framework, and Method.

INTRODUCTION

In the world where information enters in the vast world wide web and spreads to all continents, we can know very fast, in a general way, about disasters and accidents that happen on the other side of the world. These events could be both natural disasters, such as the tornado that devastated the city of Moore, near Oklahoma City, in 2013. Or, as accidents caused by human or technical failures. Every incident has a great impact on society, so there is a need to interpret the signals that are generated and happen imperceptibly. In this way, only with the planning of responsible organizations or the awareness of the population and decision makers, it will be possible to build preventive actions for emergency situations.

In emergency situations, experts make complex decision characterized by high risk, time pressure, dynamic environment, multiples involved, goal poorly defined, and low structured problems (Orasanu and Connolly, 1993; Hutchins and Kendall, 2011). This kind of decision lead normally to unpredictable consequences, because the work has to be done by a decision maker that has an overload of his cognitive capacity and functions, and the decision to be made presents characteristics that contribute to a poor analysis (Dirr et al., 2015). The literature provides some strategies to deal with the management of a decision process (Orasanu and Connolly, 1993; Klein et al., 1993), and most of them can be applied to complex decisions. However, to execute these strategies it is necessary time and available resources that are not ever possible in an emergency scenario. Considering it, it is necessary to investigate and analyze the decision characteristic and environment to avoid results against the initial goals.

According to Ochoa et al. (2006), in an emergency domain, "an investigation normally follows any incident in order to discover the causes of the emergency, evaluate the effectiveness of the response, and generate recommendations for future preventive actions". In this context, we consider the need to find ways to prevent undesirable events, respond to warnings and investigate their causes, considering the planning of a complex decision making. In other words, this paper focus on the difficulty suffered by decision makers in projected impacts of a complex decision in an emergency domain. To address this need, models that use a knowledge organization, respecting the phases of prevention, response and investigation of complex decision impact on emergency situations are necessary.

For the purpose to support decision makers to analyze complex decisions in emergency domain and project impacts of these decision in the future, this paper proposes a conceptual framework called PIED. This Framework was created following the phases proposed by the method GCF to construct a General Conceptual Framework, presented in this paper too. It is understood that if it is known the elements that characterize impact of a complex decision, the projected of these impacts becomes viable to be defined and decision makers become supported to investigate and analyze the complex decision considering the impact aspect on the emergency domain. To the best of our knowledge, this is the first study in literature that characterizes projected impacts in emergency domain considering the knowledge and experience of decision makers and complex decision structures.

This paper is divided in sections. The related works section presents a review of projected impacts on emergency domain and present some background and important definitions. The next section proposes and discusses a method to create a conceptual framework. Based on the method, the following section named "Conceptual Framework of Projected Impact on Emergency Domain (PIED)" showed the creation of a framework specialized in emergency domain. The last section concludes the paper.

RELATED WORKS

Impact is defined as a "measure of the tangible and intangible effects (consequences) of one thing's or entity's action or influence upon another" (BusinessDictionary, 2017). Bringing this definition to decision environment, Hammond et al. (2002) consider it and affirm that to achieve smart choices it is necessary to compare the merits of the known alternatives, assessing how well each one satisfies the decision fundamental goal. Discuss and analyze impact decision is a way to understand the consequences of the actions, objectives, decision structure and decision problems. Projected impact is an action performed by decision makers to minimize unexpected consequences after the decision implementation. This action is performed during the decision process. Some authors defend that it is possible to analyses the consequences of a decision implemented through the decision process monitoring, and establish a mitigation action in run time (Hammond et al., 2002). For this strategy, it is necessary to wait the materialization of the impact to introduce solutions for the decision impact on the environment, material resources and humans. On the other hand, there are other works that support an impact analyze beyond an inference and quantitative results. It is possible to find on literature works that discuss decision impact still in the beginning of decision analyses, like on the decision process planning phase (Hammond et al., 2002; Shattuck and Miller, 2006). However, most of researches in this area do not highlight details about how to effectively project impacts in practice, mainly the impacts of complex decisions. Most of them, deal with impacts projection in a subjective way, intrinsic to the decision maker's experience and their mental correlations regarding decision-making. On this work the definition of complex decision is substantiated on Naturalistic Decision Making theory that describe how decision makers make decision in real world complex domains (Orasanu and Connolly, 1993; Klein and Klinger, 1991).

Regarding emergency domain, tools to support projected impacts usually use geographic information systems to combine the relevant data and overlay the impact of the disaster. Regarding this combination, it is possible to identify population, infrastructure and resources affected immediately and also, those affected subsequently by the disaster. Some examples of such tools are: National Atmospheric Release Advisory Center (NARAC) facility at Lawrence Livermore National Laboratory for modeling hazardous atmospheric release (NARAC 2016), Radiological Assessment System for Consequence Analysis, Version 4.3.2 (RASCAL 4.3.2) developed by U.S. Nuclear Regulatory Commission's (NRC's) for studying the atmospheric radiological material release (USNRC 2016), and building fire simulation tools developed at National Institute of Standards and Technology (NIST, 2016).

Jeznach et al. (2016) presents a framework for making decisions about emergency response and remediation actions using hydrodynamic and water quality models to understand the fate and transport of potential contaminants in a reservoir and to develop appropriate emergency response and remedial actions. In the event of an emergency situation, prior detailed modeling efforts and scenario evaluations allow for an understanding of contaminant plume behavior, including maximum concentrations that could occur at the drinking water intake and contaminant travel time to the intake. The modeling study highlights the importance of a rapid operational response by managers to contain a contaminant spill in order to minimize the mass of contaminant that enters the water column, based on modeled reservoir hydrodynamics.

Fisman and Tuite (2014) used a mathematical model considering 2014 West African Ebola epidemic to simulate the quantity of vaccine needed to substantially decrease epidemic size, and also to simulate the impact of vaccination timing and dosing with a hypothetical vaccine on the future contours of the epidemic. The authors considering different assumptions around timing of vaccine availability to understand the potential impact of vaccination on epidemic trajectory. As result, authors concluded that effective vaccination, used before the epidemic peaks, would be projected to prevent tens of thousands of deaths.

Coles et al. (2016) designed and executed six experiments. In each experiment a particular component of how agencies make partnership decisions in a disaster environment was measured, aiming at develop a model of how such decisions would affect operational efficacy.

The investigation proposed in this paper differs the works cited above through a method to orient a Framework constructions, which provides a systematization of actions. The role of this Framework is to allow the decision makers projected impact of complex decisions inside emergency situations. Through this Framework it will be possible to specialist on decisions to characterize impact in this scenario and visualize the probable consequences of their actions before the decision is made. The proposed method and Framework deal with aspect presented on the environment and on decision maker characteristics. At the end of decisions analyze, the decision maker continue be the one responsible to choose the more indicated alternative of action, considering the options proposed by him.

A METHOD TO CREATE A CONCEPTUAL FRAMEWORK

To construct a framework, according to Araujo and Borges (2012), it comprises three subactivities: elicitation of requirements from the literature or interview with specialists, design of the framework from the information elicited in the previous sub activity, and elaboration of a method to use the framework. This paper proposes a method to construct a General Conceptual Framework (GCF), where its specialization acts in the emergency domain. This method (Figure 1) is composed by a set of eight phases inspired in Araujo and Borges (2012), and considers the reuse of existing methods and concepts to characterize the domain to be explored. Among the phases, there are: (I) Conceptual Framework planning; (II) Investigation/Adaptation of existent methods; (III) Information research of interest concepts; (IV) Definition of framework categories; (V) definition of framework conceptual structures; (VI) Establishing interaction with stakeholders; (VII) Conceptual Framework construction; (VIII) and Disclosure of the conceptual Framework.

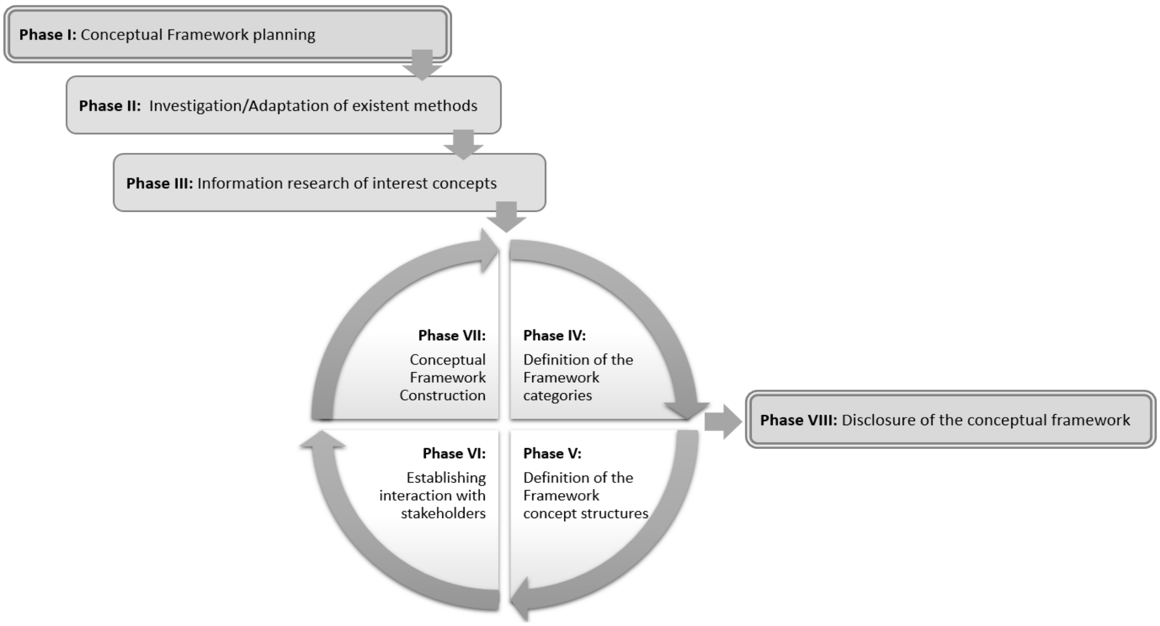

Figure 1. Method to construct a General Conceptual Framework (GCF).

Figure 1 shows the sequences of actions that compose the method, and which should be established for the construction of a Conceptual Framework. In Figure 1, it is possible to observe that the initial phase, which provides the planning of Framework construction actions, highlights the goals to be achieved and the products to be built, including those involved in the construction and information gathering. The next phase is the adaptation of existing Framework construction methods. Thus, the GCF method was adapted from the Araujo and Borges (2012) method with the insertion of new steps and adaptation of already existing steps, other methods can be better adapted according to the result of interest desired. Phase II, however, is optional, it is up to the constructor of the Conceptual Framework to predict it in its actions or to adopt the other phases of the GCF method in the construction of its conceptual Framework. Phase III includes the elicitation of information on areas of interest that may occur through the literature, practical manuals and experience of those involved in the Framework construction. The fourth phase establishes the categories to be defined to characterize the elements of the Framework, based on the results obtained in the previous phase. Part of this phase is also to refine the survey of the previous phase, focusing on aspects of interest for the categories definition. Using the results of Phases III and IV, the conceptual elements of the Framework (Phase V) are defined and can be expressed in the form of metamodels, ontologies or some other form of conceptual representation.

Building a conceptual framework, consistent with reality, requires a direct interaction with its potential stakeholders. In this way, Phase VI is proposed in the method, where stakeholders are heard about the area of interest of the Framework. At this phase, interviews or questionnaires are planned as a way of eliciting information. Phases IV, V, VI, and VII are cyclic and present results that are dependent on each other. The products generated by these phases are built incrementally and with parallelization in activities. The conclusion of the Conceptual Framework (Phase VII) happens when the actors, involved in its construction, reach a satisfactory representation result of the Framework, according to the goals initially outlined in Phases I and II. Phase VIII is about making the proposed Framework public, so that it can be applied in real solutions and not just as a test. The method proposes a set of phases to support the construction of a Conceptual Framework. It will be up to the person responsible for its execution to define the details of each phase and to implement them. The method output requires a Framework presentation structure to be displayed. The following section presents a practical application of the GCF method for the construction of the Conceptual Framework for impact projection in the emergency domain.

CONCEPTUAL FRAMEWORK OF PROJECTED IMPACT ON EMERGENCY DOMAIN (PIED)

Based on the GCF method, the construction of the Framework for Projected Impacts on Emergency Domain (PIED) was built (Figure 2). To the Phase I the guidelines to be achieved in the construction of the PIED Framework were established. The main goal is to establish a mechanism to support decision-makers in complex environments. In this way, they can project impacts of actions taken, still in the planning phase of the decision.

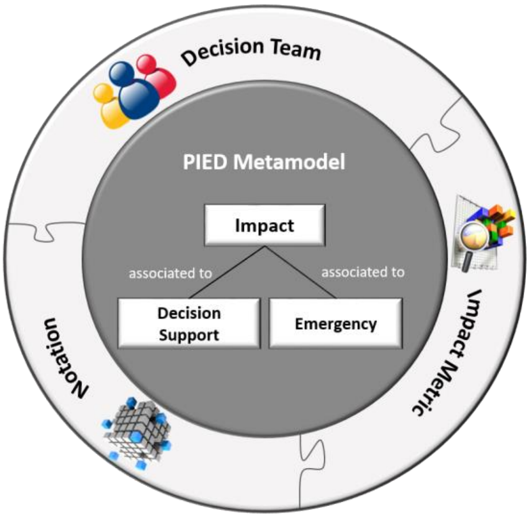

Figure 2. Conceptual Framework of Projected Impact on Emergency Domain (PIED).

For the construction of the present Framework, the proposed GCF method was used. All its phases were performed, except for Phase II, since the current method was sufficient for the proposed aim. In Phase III, a conceptual survey on the concept Decision was carried out, more specifically were considered the naturalistic decisions, complex and group decisions concepts, beyond the emergency domain. In this survey were considered the definitions of these concepts, their characterizations found in the literature and models to support decision making. The result of this survey generated a set of categories of PIED that was evolved in elements characterizing the Framework, composing the result of Phase IV of the GCF method.

Figure 3 shows the execution of the GCF method's Phase IV to construct the PIED. In this table, there are the categories that express projected impact idea, the categories characterized elements, and the way how the projected impact could be materialized to support decision makers in their tasks. Categories are elements that show the central idea of the framework proposed. The characterized elements show details about the categories. In PIED case, these are the elements that define how complex decision making occur on emergency domain, and what are the possible elements that support projected impact before the implementation of the decision. Support are the practical action, based on characterized elements, that must be done by decision makers to projected impact on emergency and complex decision. In PIED case, the support considered are the: (i) collaboration between decision makers, volunteers and professionals; (ii) the definition of an impact metric to help decision makers visualize and understand the impact of a decision on the environment and on others decisions; and (iii) the establishment of a notation to represent the projected impact configuration.

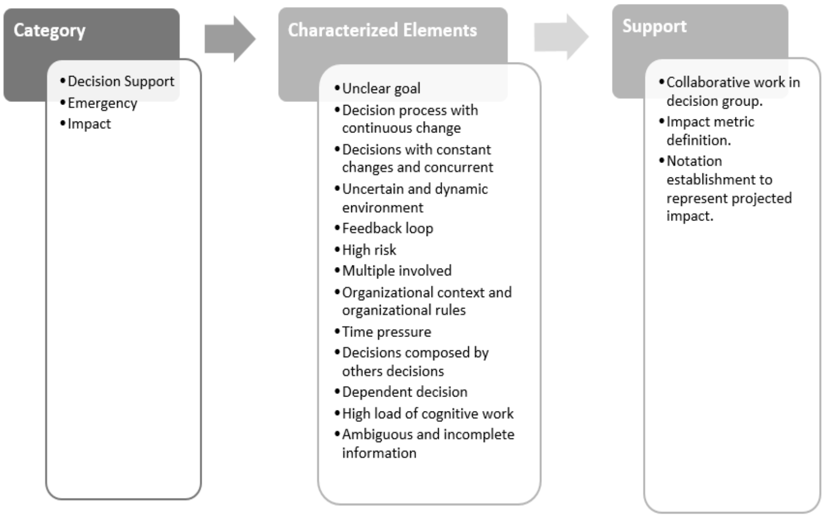

Figure 3. Execution of method GCF' Phase IV in Framework PIED construction.

In Phase V, the characterizing elements of Figure 3 were evolved in conceptual structures. These structures will compose the materialization of the PIED Framework through the impact projection constructs. Its role is to detail the constructs that, when instantiated, will compose the impact projection model. The main structure of the projection of impacts occurs, through the externalization of: the possible scenarios of a decision to be made; feasible alternative actions in the predefined scenarios; the implications of each alternative; the impact of each alternative in the predicted scenario; and the elements that characterize the decision. These aspects were proposed based on the previous GCF phases results. The phase VI of GCF method compose the detailing of the PIED concepts, considering the specialist view. The last two phases of GCF, the aim is to conclude a representation of the Conceptual Framework and make it known. These goals will be discussed in a future work.

CONCLUSION

This research had the role of supporting decision makers acting inside emergency domains, in projecting complex decision impacts before its implementation. Since unforeseen events in emergencies can generate uncontrollable consequences, knowing and analyzing a set of potential impacts of the decision, can support the decision maker in the exercise of his activities, reducing his cognitive and functional overload. In this way, this paper contributes with a method to create Conceptual Frameworks (GCF) and the development of an instantiation of this method, named PIED Framework. The PIED framework support decisions makers to analyze complex decisions in emergency domain and project impacts of these decision in the future. As a result of the conducted evaluation, the method and the Framework characterized the impacts projection on emergency environment.

As future work, we can highlight the evolution of the PIED Framework, considering the experts knowledge and their practical on decision making in emergency environment. It is possible to represent the detailing of the PEID concepts by a metamodel, considering the relationship too. This metamodel can be enriched by the actions of impacts discovered by the contact with experts. The aim is to investigate the evidences about the feasibility of the adherence of the proposed framework and its metamodel regarding the actions taken in practice by decision makers.

Another aspect to consider in a future work is the deepening discussion about the indication of collaborative activities to support this kind of projection. Evolutionary iterations of the framework have the potential to generate increasingly good results in terms of its ability to support decision makers. In order to require less dedication of the decision makers in the use of the PIED Framework, a possible path is to build decision-making group orientation processes in the establishment of the projection, and the construction of models and reports in a dynamic. In addition, further research can explore differences in projection of impacts in different areas.

To add value regarding the PIED framework, a web and collaborative application that supports the discussion, analysis and projection of impacts of complex decisions can be developed. In this way, it is possible to support decision-makers, specialists and collaborators who are not physically co-located in discussing and analyzing the impacts of complex decisions in emergency domains dynamically.

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Modeling of Railway Risk Inter-Relation based on the study of Accident Context

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ABSTRACT

In order to detect and control the critical potential risk source of railway more scientifically, more reasonably and more accurately in complex accident context, a knowledge modeling method of risk inter-relation is proposed based on ontology modeling of accident context. First, the mechanism of accident causation is summarized based on the accident case analysis. Then, the knowledge model of accident cause is built based on ontology theory, including the ontology model of two context instances. Last but not least, the risk inter-relation rules with different dimensions of inter-relation patterns are inferred based on the instantiation of ontology model. The two context instances are used to illustrate the identification process of risk inter-relation. The results prove the rationality of the method, which can provide a reference for the precise railway risk prevention.

Keywords

Railway risk source, accident context, ontology modeling, risk inter-relation.

INTRODUCTION

In the domain of railway risk detection and prevention, the general researching method is to analyze existing accident reports, build accident tree and find out the risk sources which led these accidents. When the similar risk sources occur, the risk management system will send a warning. However, the current railway traffic risk prediction rate is low; early warning response cannot be multi sectoral linkage, often a single sector response to a single risk warning. Why is the risk forecast low? Why respond to a single department? To begin with, the analysis and simulation of accident did not consider complex context, which does not take the heterogeneous knowledge into account, e.g. environment and human behavior. Besides, accident analysis is a kind of after-event analysis method; the risk source can be detected only after the accident; the potential risk sources which may lead to future accident cannot be found by this kind of after-event analysis. Finally, railway risk management is a complex risk linkage system, but the potential inter-relation of risk sources is often ignored.

Speaking about context, (Moray 1994) proposed that all behavior and performance takes place in a setting or a context, and ergonomics/human factors must understand and account for this context, which increasingly is that of complex socio-technical or even social systems. What is useful for analysis of complex systems, parent-child or sibling systems is some form of systematic representation which shows where and how system boundaries operate and how each can provide context for others. (Rasmussen 2000; Rasmussen 1997) well known risk management framework for instance has been used by several authors to explain the layers of complex systems, e.g. (Waterson 2009). As for as context is concerned, this is critical for the railway.

Early risk management theory treats the occurrence of an accident as an independent event, which means that one risk source corresponds to one accident, and less attention is paid to the inter-relation of the cause of accident. Under this circumstance, only the risk source of the accident that had already happened can be effectively controlled, but the potential risk source and the risk inter-relation cannot be identified. However, in reality, there is much more inter-relation between risk factors. The occurrence of accidents is often due to the integration of multiple risk factors. The risk factors interact with each other in different places, at different times and by different sequences, covering the whole process of the occurrence of accident. Furthermore, any stages of the risk management process may create new risk sources. For example, in the stage of emergency response, the emergency staff do not treat the risk event in time, then it becomes a new risk source that eventually leads to the escalation of accident level. Consequently, risk factors may also lead to a chain of accidents; accident chain means one event is closely related to another event, and the end of the chain is the accidents and losses.

The development trend of modern risk management has transformed passive risk control into initiative risk prevention, while mining the potential risk inter-relation is the key to detect the potential risk sources, and then achieve the precise risk prevention. However, the existing accident case analysis will be helpful for discovering the potential risk sources, the analysis of each risk chain and accident chain is needed to identify the inter-relation of accident cause. Through the careful accident case analysis, if the risk inter-relation is identified, then the most critical potential risk source is detected.

In recent years, (Aitken et al. 2010; Fang et al. 2012; Fang and Marle 2012; Song and Cai 2012) have carried out the research on the correlation between risk sources. (Marle and Bocquet 2013) build the interactions-based risk model for project management by using RSM (Risk Structure Matrix) method and confirm the strength of interactions between different risks with AHP (Analytic Hierarchy Process). (Yang and Zou 2014) build a social network model considering the interactions of project risks and determine the optimal strategy set of risk response to deal with the interactions of different risks. (Cao et al. 2015) conclude the concept of risk chain and use the non-subjective method to analyze the evaluation information of the interrelationship among schedule risk factors that are given by the expert group. To summarize, these research works mainly focus on using mathematics method to identify some simple relation patterns. Knowledge modeling is not involved in the domain of railway risk inter-relation identification. The problem of potential risk source detection in complex accident chain context is still not be effectively solved.

In conclusion, in order to detect and control the critical potential risk source of railway more scientifically, more reasonably and more accurately in complex accident context. This paper proposes a knowledge modeling method based on ontology modeling of accident chain context, which can be briefly illustrated as follows:

- To begin with, the accident causation mechanism is summarized by the analysis of the context elements from accident cases in section 3 and section 4.
- Besides, the knowledge model of accident cause is constructed based on ontology theory in section 5.
- Finally, the risk inter-relation rules with different dimensions of inter-relation patterns are inferred based on the instantiation of ontology model. Two context instances are used to prove the rationality of the method in section 6.

RELATED WORKS

All the articles in related works are selected in Web of Science by key words “railway”, “risk”, and “context” and published from 2013-2017. After manual selection, 54 articles are narrowed down to 25 articles. (Wernstedt and Murray-Tuite 2015) reports how the accident appears to have changed over time the tradeoffs among safety, speed, frequency of service, cost, and reliability that the transit users stated they were willing to make in the post-accident period. According to those articles, risk management could be summarized as three phases: analysis, model, and assessment (post-accident period).

In analysis phase, one task is to find **modeling factors** which is the inputs of next phase. Human factor is the most important part. (Grote 2014) argued that in order to change this situation human factors/ergonomics based system design needs to be positioned as a strategic task within a conceptual framework that incorporates both business and design concerns. (Tey et al. 2014) compares driver behavior towards two novel warning devices with tow conventional warning devices at railway level crossing using microsimulation modelling. (Ghomi et al. 2016) identifies the main factors associated with injury severity of vulnerable road users involved in accidents at highway railroad grade crossings using ordered probit model, association rules, and classification and regression tree algorithms to accident database (user view, not worker view). (Saat et al. 2014) talked about environment factor. It describes a quantitative, environmental risk analysis of rail transportation of a group of light, non-aqueous-phase liquid chemicals commonly transported by rail in North America. (Liu et al. 2014) developed an analytical model to address the tradeoffs of broken rails among various factors related to rail defect inspection frequency, so as to maximize railroad safety and efficiency. Another task is the **analysis method**. (Peng et al. 2016) presents an analysis technique called timed fault tree which extends traditional fault tree analysis with temporal events and fault characteristics (assessment). (Castillo et al. 2016) provides a new Markovian-Bayesian network model to evaluate the probability of accident associated with circulation of trains along a given high speed or conventional railway line with special consideration to human error. This method is better than fault tree to break the limitation of variables' dependency. (Azad, Hassini, and Verma 2016) propose an optimization-based methodology for recovery from random disruptions in service legs and train services in a railroad network. This model is solved for each service leg to evaluate a number of what-if scenarios.

In the model phase, most work used mathematics model. (Fan et al. 2016) proposed a combinational method of analytic hierarchy process and fuzzy comprehensive evaluation to assess hazards in a complex maglev bogie system associated with multiple subsystems' failures. (Wu et al. 2014) developed a methodology to model the passenger flow stochastic assignment in urban railway network with the considerations of risk attitude. (Ghazel and El-Koursi 2014) conduct a risk assessment comparative study involving two main types of automatic protection systems, the first using a pair of half-barriers and the second with four half-barriers. (An et al. 2016) presents a modified fuzzy analytical hierarchy process that employs fuzzy multiplicative consistency method for the establishment of pairwise comparison matrices in risk decision making analysis. (Adjetey-Bahun et al. 2016) proposed a simulation-based model for quantifying resilience in mass railway transportation systems by quantifying passenger delay and passenger load as the system's performance indicator (resilience). (Guo et al. 2016) presents a comprehensive risk evaluation method based on a fuzzy Petri net model for long-distance oil and gas transportation pipelines. (Haleem 2016) identifies the significant predictors (e.g., temporal crashes characteristics, geometry, railroad, traffic, vehicle, and environment) of traffic casualties and no injury. The method applies both the mixed logit and binary logit models. (Vaidogas, Kisezauskiene, and Girniene 2016) assesses individual segments of road and railway network by estimating risks posed by potential fires and explosions on road and rail.

For the assessment phase, (An et al. 2016; Zhang et al. 2016; Guo et al. 2016; Zhao, Stow, and Harrison 2016; Chen et al. 2016; Peng et al. 2016; Vaidogas, Kisezauskiene, and Girniene 2016; Ghazel and El-Koursi 2014) used analysis method and modeling method to achieve risk assessment goal. From tool or implementation angle, (Lira et al. 2014) used a data analytics workflow to compile an incident risk index that processes information about incidents along railway lines and display it on a geographical map. (W.Y. Chen, Wang, and Fu 2014) developed terrain drop compensation technique, linear regression technique and calculating local maximum Y-coordinate object points to detect the risk area of a railway crossing. (Zhang et al. 2016) presented an adaptable metro operation incident database for containing details of all incidents that have occurred in metro operation. (Figueres-Esteban, Hughes, and van Gulijk 2016) focuses on visual text analysis techniques of Close Call records to extract safety lessons more quickly and efficiently.

To summarize, two problems remain to be solved:

- Modeling factors are not structured as a system. Modeling factors of context should be organized by concept-relations.
- Modeling method are mathematics method, knowledge base is not involved in this domain. But as a complex system, knowledge modeling is needed, especially for the potential risk inter-relation mining.

ACCIDENT CONTEXT ANALYSIS

In 1994, Schilit and Theimer proposed the concept of context-aware for the first time, it was described as, "the location, identity and change information of people and objects in the surrounding environment". Then the concept of context had been largely considered in research, but the more accurate mentions that "the context is any information that can be used to identify entities such as people, places or objects et al. and the information that is related to the interactions of users and computing system" (Abowd and Dey, 1999). Modern knowledge theory holds that context is a typical implicit information. Because of the existence of the context, there is a correlation between knowledge, knowledge itself makes sense (Li et al., 2014).

Context information is rich in content, including computing context (network connection, communication cost, communication bandwidth, peripheral resources), user context (user profile, location, social status), physical context (light, noise, traffic conditions, temperature), time context (time, week, month, season) and other types (Chen and Kotz, 2000). The description of the types and characteristics of the accident context will vary slightly from one industry to another and there is no uniform description of the criteria. In the field of railway safety management, the existing context description of large-scale accident or small-scale security incident mainly consists of seven elements, and they are analyzed in detail as follows:

- *Time*: It describes the time when the accident or security incident happen.

- *Place*: It describes the place where the accident or security incident happen.
- *Risk factor*: It is described as the potential cause of accident. From the point of view of system theory, the risk factors of railway are divided into four categories as follows, the detailed index system is illustrated in Figure 1:
    - *People* is the subject of the railway safety management system.
    - *Equipment* is the general term for all objects that are controlled by people.
    - *Environment* is the specific working conditions of people and equipment.
    - *Management* is the means to coordinate people, equipment and environment.

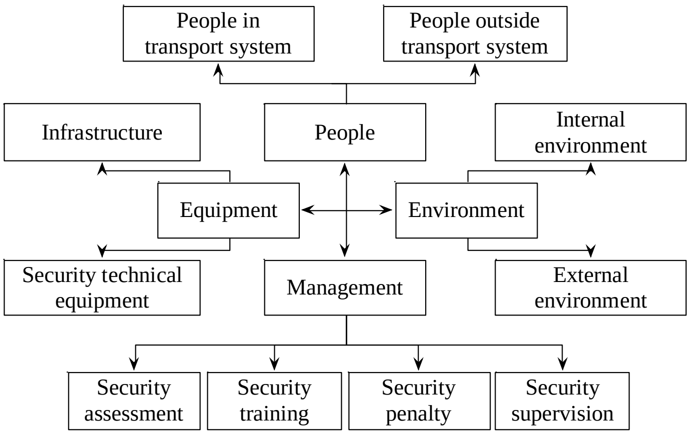

Figure 1. Risk Factor Index System of Railway

- *Accident*: The American Society of Safety Engineers defines accidents as, "An accident is a contingency that occurs abruptly, forcing a person's purpose of action to be temporarily or permanently interrupted, and sometimes resulting in personal injury or social damage".
- *Accident level*: The classification of the accident level is generally closely related to national laws and regulations. According to the "*Regulations on emergency rescue and investigation and handling of railway traffic accidents"* (The State Council of the PRC bulletin, 2007), on the basis of different situations of casualties and economic losses, accident is divided into four categories: extraordinarily serious accident, serious accident, major accident and general accident. Besides, according to the level of accident loss from the maximum to the minimum, general accident is divided into A-level accident, B-level accident, C-level accident and D-level accident (see Figure 2).

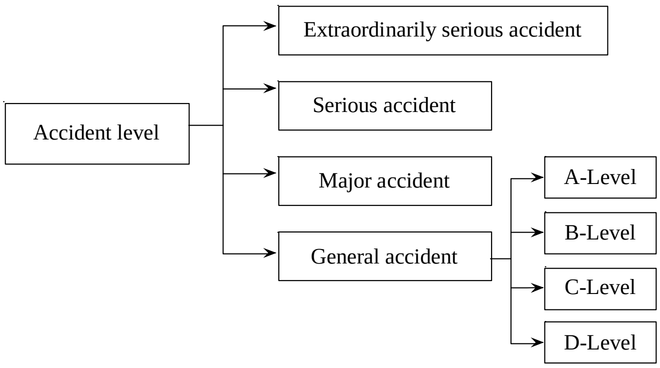

Figure 2. The Classification of Accident Level

- *Accident unit level:* It describes which unit of the whole organization will take responsible for the accident. To a certain extent, the level of the unit illustrates the sphere of influence and severity of the accident. Take the organizational structure of a railway company as an example, it represents the division of the responsibility unit level of accident in the company (see Figure 3).

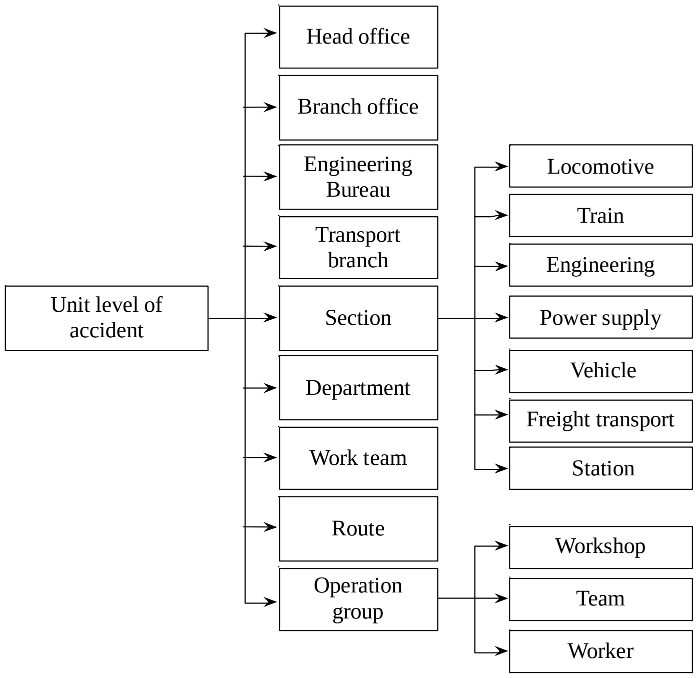

Figure 3. The Responsibility Unit Level of accident in a Railway Company

- *Emergency performance*: It describes the context of emergency treatment after accidents. It is worth mentioning that new risk sources may be created if the emergency is not handled properly.

ACCIDENT CASE ANALYSIS

In railway traffic area, the causes of accidents are manifold and complex, and at the same time there are rules to follow. Accident case management is one of the important contents of railway safety work. There are a large number of accident chain cases stored in the accident case database, which provides a base of knowledge acquisition for the analysis of the causes of railway accidents in complex contexts. The accident chain case provides many important accident context information such as time, weather, location, participant, accident level and so on for digging out the cause of the accident and the potential risk sources.

In reality, the accident may be caused by one risk source, may be caused by the simultaneity of two risk sources, and may be caused by the succession of multiple risk sources. Through the accident case analysis, it can be found how the risk sources are created, how the risk factors interact with each other and what the mechanism of accident cause is. What's more, it is also essential to analyze and decompose the risk chain and the accident chain of each accident case in detail. As the most important part of chains to be found, the most crucial potential risk sources can be controlled or eliminated.

There are 101 case reports of railway accidents from 2002 to 2012 provided by a railway company. The case reports include a short description of the accident, the process of the accident, emergency actions, the main cause of the accident and the responsibility unit or personnel. They will be thoroughly analyzed for the mechanism of accident cause based on the previous analysis of seven context elements. The accident context information and the process of accident case analysis are organized and recorded for a pattern as illustrated in Table 1.

Table 1. The Record Pattern of Accident Case Analysis

Number	Time	Location	Risk Factor	Accident	Accident Level	Unit Level	Emergency Performance
……	……	……	……	……	……	……	……

The following three patterns of accident cause can be summarized after accident case analysis, and an instance of every pattern will be illustrated as follows:

- Pattern A: Single risk factor leads to an accident.
  This kind of accidents are small-scale security incidents in general with less loss. The instance of pattern A (see Table 2) refers to an accident case of electricity major, about which a personnel on-duty operated

illegally against the security operation systems and thus led to the turnout error. Due to the timely repair after the accident, there was no risk accumulation to cause the other accident.

Table 2. An Instance of Pattern A

Time	Location	Risk Factor	Accident	Accident Level	Unit Level	Emergency Performance
1/24/2005	North station	People	Turnout error	D	Station	Timely repair

- Pattern B: An accumulation of multiple risk factors lead to an accident.
  The instance of pattern B (see Table 3) refers to an accident case of power supply major, about which different kinds of risk factors have emerged one after another, a number of risk factors accumulated without timely detection and control, eventually which lead to an accident.

Table 3. An Instance of Pattern B

Time	Location	Initial Risk	First Accumulation	Second Accumulation	Third Accumulation
10/14/2011	Substation	Equipment	People	Environment	Management

The Fourth Accumulation	Accident	Accident Level	Unit Level	Emergency Performance
People	Circuit breaker tripping	D	Section	Error treatment scheme

- Pattern C: Multiple risk factors lead to a number of accidents, resulting in an accident escalation.
  The instance of pattern C (see Table 4) refers to an accident case about which a small sub-accident occurred due to the negligence of the staff at the beginning. Then the second sub-accident occurred because of the management problem after one risk accumulation. But all the risks and incidents emerged were not timely and promptly controlled. Eventually, three risk accumulation and two small incidents lead to an accident escalation.

Table 4. An Instance of Pattern C

Time	Location	Initial Risk	First Sub-Accident	First Accumulation	Second Sub-Accident
5/10/2013	North station	People	Bad shunting	Management	Cancel shunting route

Third Accumulation	Accident Escalation	Accident Level	Unit Level	Emergency Performance
People	Two cars collided	C	Branch office	Without timely controlled

ONTOLOGY MODELING OF ACCIDENT CAUSE

Ontology model can provide clear consistent semantic description for context information from different sources. It can also support automatic reasoning for abstract higher-level contexts from underlying information that is full of uncertainty, imprecision and dynamic change feature (Bettini et al., 2010). Protégé (Horridge et al., 2004) is widely used to create, populate, update and visualize ontology. In this paper, it will be used to create the ontology model of accident cause. OWL (Bechhofer et al., 2004), which has a unified grammatical format and explicit semantics, it will be adopted as the formal description language of the ontology model.

In order to further search for the inter-relation of risk factors, a number of accident cases with complex accident cause and high accident level will be selected to collect and analyze the context information. The ontology model of accident cause (see Figure 4) is constructed by the process of the definition of core concepts and relationships, the construction of ontology architecture, the addition of instances and the evolution of ontology model. Owing to spatial confined, the relevant properties of concepts and instances are omitted from the model. The ontology model reflects the accident cause mechanism; the core concepts and relationships of the model are illustrated as follows:

- *Accident*: It describes the accidental damage or destruction in the process of railway traffic driving.

Generally, the occurrence of accidents is the result of the combined effects of many risk factors.

- *Risk source*: It describes the root cause of the railway traffic accident. The categories of risk source include the class of people, equipment, environment and management. Through the analysis of the real railway accident cases, it is found that the concept of risk source itself has the accumulation relationship, that is, accident is caused by the accumulation of multiple risk sources.
- *Sub-accident*: It describes an accident in the accident chain, and the combination of multiple sub-accidents constitutes a terminal accident. It is generally a lower level of security risk incidents. However, it is found that the occurrence of sub-accident represents the accident cause has a more complex pattern in the process of accident case analysis. To be more specific, this kind of pattern of accident cause is that risk source leads to sub-accident, the terminal accident of high level is caused by the accumulation of multiple risk factors and the escalation of multiple sub-accidents. Therefore, the concept of sub-accident itself has the escalation relationship.

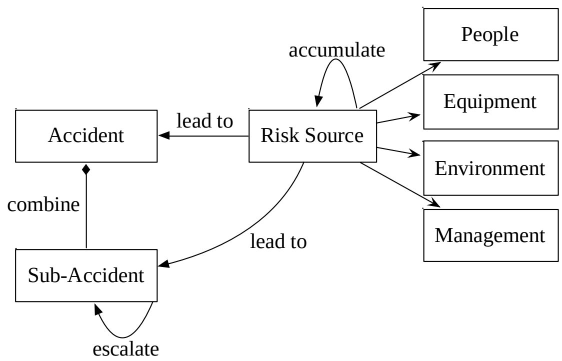

Figure 4. The Ontology Model of Accident Cause

In the ontology model of accident cause, the classification of risk source and the relationship between risk sources are the most complex part. The concept of risk sources of people is selected as an example, and the concept system of people in ontology model is illustrated in Figure 5. The risk source of people is divided into behavior risk and characteristic risk. According to the accident case analysis results, behavior risk includes some personal behavior risk such as duty neglect and non-standard operation, as well as group behavior risk such as construction and group work. Besides, security consciousness and working condition of characteristics risk are the most common cause of the accident.

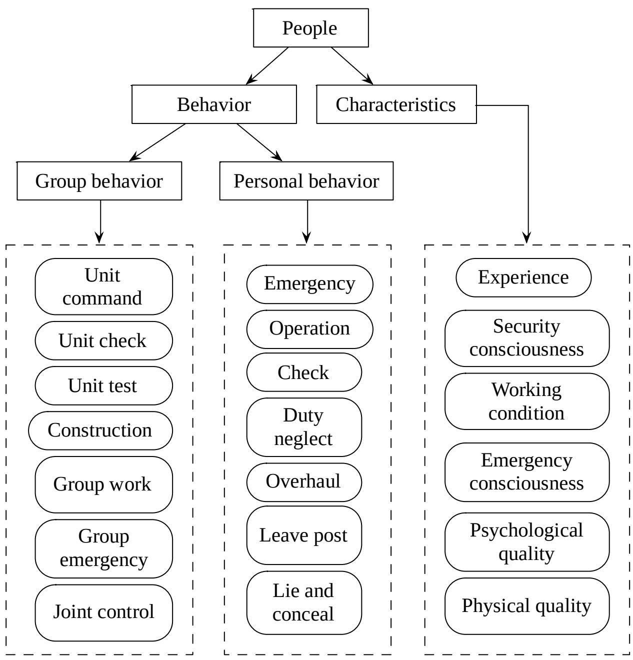

Figure 5. The Concept System of People in Ontology Model

The instance of pattern B (see Table 3) and the instance of pattern C (see Table 4) that given by the previous section are selected as the examples to construct the ontology model of instances (see Figure 6 and Figure 7), which is named instance B and instance C.

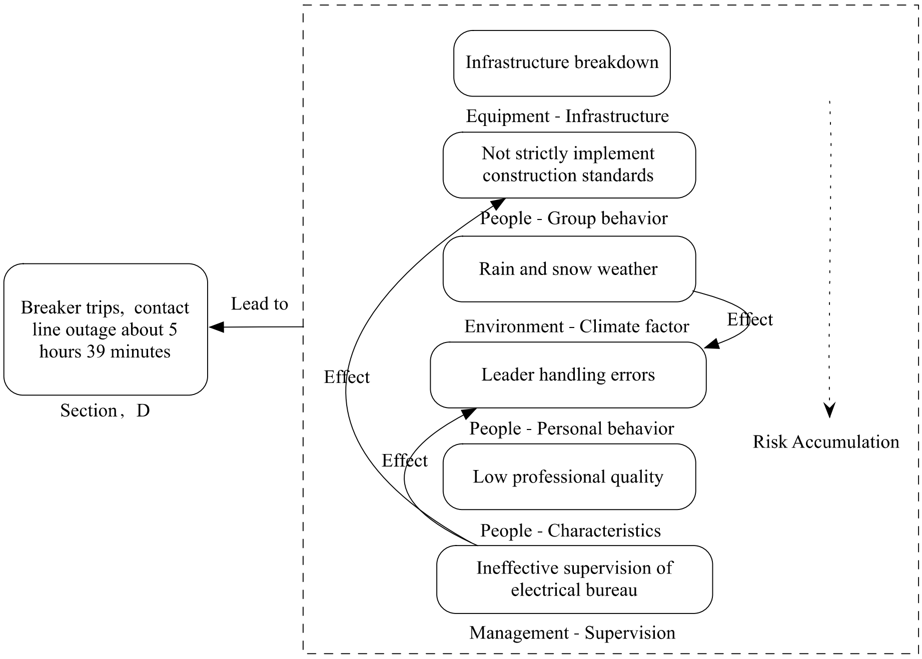

Figure 6. The Ontology Model of Context Instance B

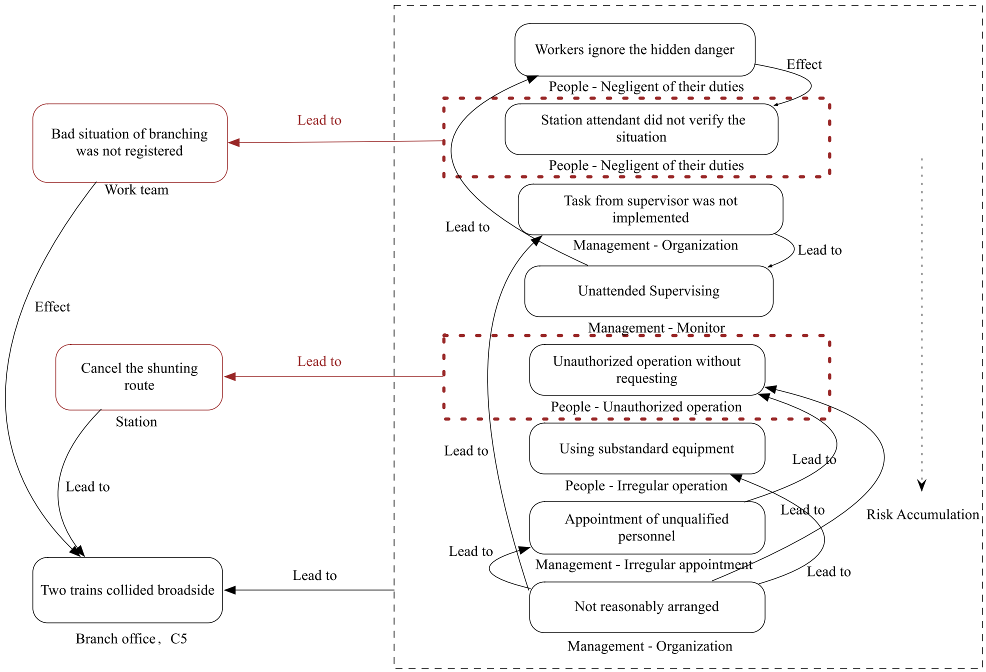

Figure 7. The Ontology Model of Context Instance C

IDENTIFICATION OF RISK INTER-RELATION PATTERNS

The two accident context instances in the last section show that risk source as the root cause of accident does not exist independently. The occurrence of accident is due to the integrated effect between multiple risk factors. Consequently, the identification and mining of all these inter-relation patterns is the focal point of risk prevention. As illustrated in Figure 8, if the potential inter-relation between two pairs of risk factors is identified, then just controlling one inter-relation point can solve two risk sources, so the repetitive control of risk sources can be avoided, the potential risk source can be controlled more accurately. What's more, since ontology provides a nice expression mechanism for context information and supports semantic reasoning, a balance can be established between context description and context reasoning. Accordingly, the rules of risk inter-relation pattern can be summarized through the ontology model when the potential risk sources are identified. The knowledge base formed by the ontology model makes the intelligent risk prevention possible.

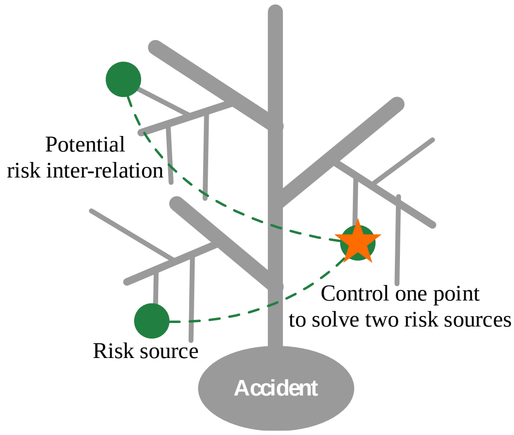

Figure 8. The Risk Prevention in Pattern of Risk Inter-Relation

The instantiation of knowledge has a unified structure and form that makes knowledge sharing, reuse and operation very convenient. The risk inter-relation analysis will be carried out by using the instantiation knowledge in the accident cause ontology. The inter-relation rules with different dimensions of inter-relation patterns can be inferred based on the instantiation of ontology model. The basic definition of risk inter-relation reasoning rules is described as follows:

i. Risk source set is R, R=(Risk(R_1), Risk(R_2), Risk(R_3) ... Risk(R_n)), n is the number of risk source.
ii. Occur() is the state function of risk source set R. Occur(R)=1 represents that the risk sources of set R occur in sequence by input order.
iii. RelationRisk() is the inter-relation function of risk source set R. RelationRisk(R)=1 represents that there is an inter-relation between risk sources of set R.

Four patterns of risk inter-relation are selected as the examples, which are illustrated as follows:

- Pattern A: The risk sources occur in the same time.
- Pattern B: The risk sources occur in the same location.
- Pattern C: Two risk sources occur in pairs.
- Pattern D: Three or more risk sources occur with combination.

Rule (1) ~ Rule (8) are the inter-relation rules for the four patterns of risk inter-relation inferred by risk inter-relation analysis. They are illustrated as follows:

- Rule (1) describes the inter-relation rules for Pattern A that two risk sources occur in the same time. If R_1 and R_2 occur in the same time, then R_1 and R_2 have the inter-relation.

$$\begin{gathered}\text{If OccurTime}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\\ \rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{gathered} \tag{1}$$

- Rule (2) describes the inter-relation rules for Pattern B that two risk sources occur in the same location. If R_1 and R_2 occur in the same location, then R_1 and R_2 have the inter-relation.

$$\begin{gathered}\text{If OccurLocation}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\\ \rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{gathered} \tag{2}$$

- Rule (3) and Rule (4) describes the inter-relation rules for Pattern C that two risk sources occur in pairs. Rule (3) illustrates if R_1 and R_2 occur repeatedly by the same sequence, then R_1 and R_2 have the inter-relation; Rule (4) illustrates if R_1 and R_2 occur repeatedly by the exchanged sequence, then R_1 and R_2 have the inter-relation.

$$\begin{gathered}\text{If Occur}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1 \wedge \text{Occur}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\\ \rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{gathered} \tag{3}$$

$$\begin{gathered}\text{If Occur}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1 \wedge \text{Occur}(\text{Risk}(R_2),\text{Risk}(R_1)) == 1\\ \rightarrow \text{RelationRisk}(\text{Risk}(R_1),\text{Risk}(R_2)) == 1\end{gathered} \tag{4}$$

- Rule (5) ~ Rule (8) describes the inter-relation rules for Pattern D that three or more risk sources occur with combination. Rule (5) illustrates if R_1, R_2 and R_3 occur repeatedly by the same sequence, then R_1, R_2 and R_3 have the inter-relation; Rule (6) illustrates if R_1, R_2 and R_3 occur repeatedly by the exchanged sequence, then R_1, R_2 and R_3 have the inter-relation.

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1\\ &\quad \rightarrow \text{RelationRisk(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1\end{aligned} \tag{5}$$

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_2\text{),Risk(R}_3\text{),Risk(R}_1\text{))} == 1\\ &\quad \rightarrow \text{RelationRisk(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1\end{aligned} \tag{6}$$

- Rule (7) illustrates if R_1 and R_2 which are in the combination of R_1, R_2 and R_3 and the combination of R_1, R_2 and R_4 occur repeatedly by the same sequence, then R_3 and R_4 have the inter-relation; Rule (8) illustrates if R_1 and R_2 which are in the combination of R_1, R_2 and R_3 and the combination of R_2, R_1 and R_4 occur repeatedly by the exchanged sequence, then R_3 and R_4 have the inter-relation.

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_4\text{))} == 1\\ &\quad \rightarrow \text{RelationRisk(Risk(R}_3\text{),Risk(R}_4\text{))} == 1\end{aligned} \tag{7}$$

$$\begin{aligned}&\text{If Occur(Risk(R}_1\text{),Risk(R}_2\text{),Risk(R}_3\text{))} == 1 \wedge \text{Occur(Risk(R}_2\text{),Risk(R}_1\text{),Risk(R}_4\text{))} == 1\\ &\quad \rightarrow \text{RelationRisk(Risk(R}_3\text{),Risk(R}_4\text{))} == 1\end{aligned} \tag{8}$$

The above-mentioned risk inter-relation rules are used for the accident context instance B and the accident context instance C as the examples. The running results are illustrated in Figure 9 and Figure 10. Figure 9 indicates the condition in which two risk sources occur by the same sequence and lead to accident. The inter-relation of two risk sources is identified by Rule (3), however the two risk sources derive from different instances but the same class that is people and management. Likewise, Figure 10 indicates the condition in which two risk sources occur by the exchanged sequence, then lead to accident. The inter-relation of two risk sources of people and equipment is identified by Rule (4).

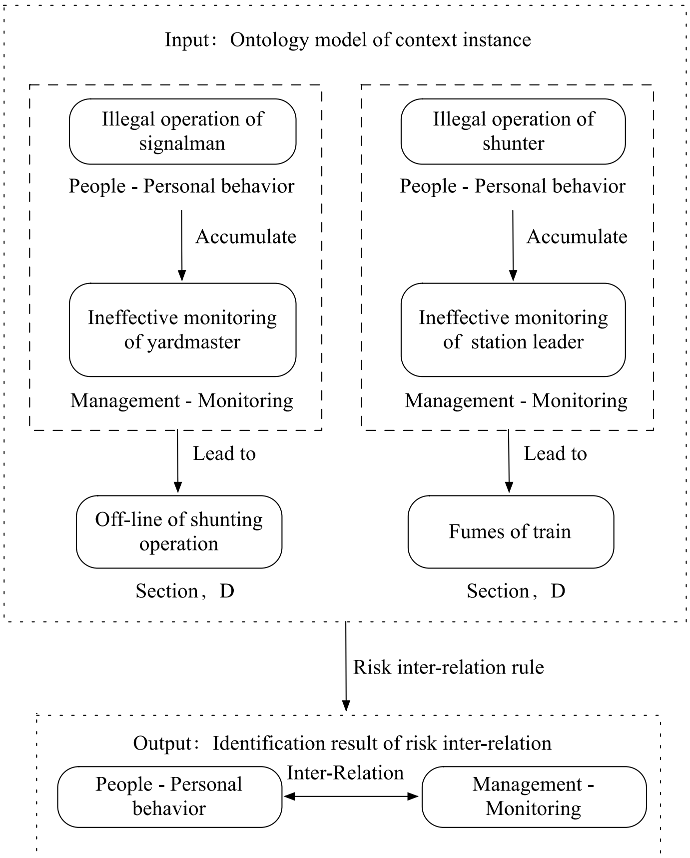

Figure 9. The Identification Process of Risk Inter-Relation in Context Instance B

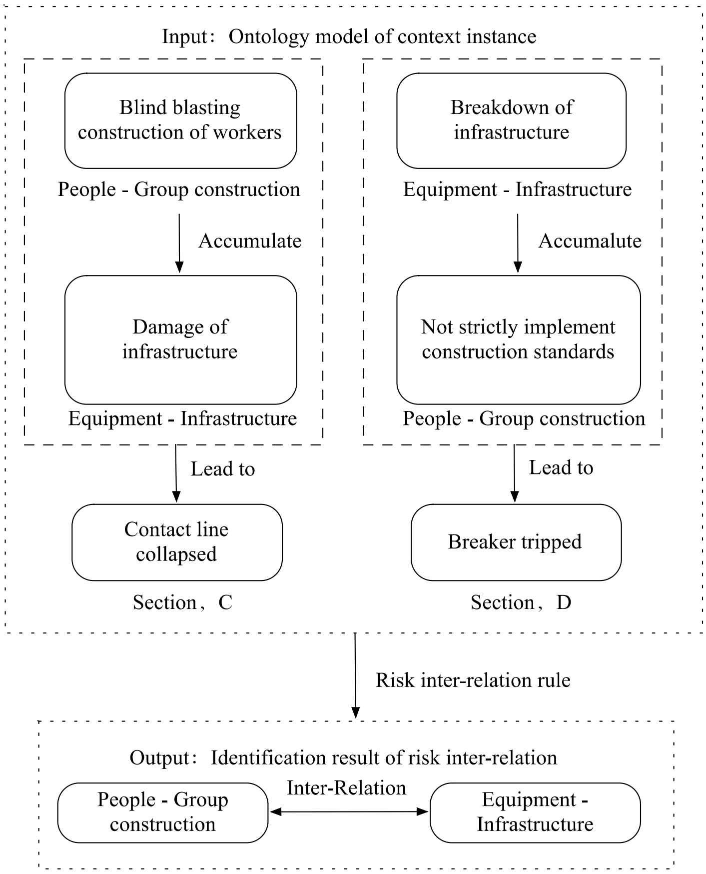

Figure 10. The Identification Process of Risk Inter-Relation in Context Instance C

CONCLUSION AND FUTURE WORK

Considering the characteristics of complex railway accident context and the difficulty of detecting potential risk source, this paper accomplished the following work to solve the problem: the description of accident context was resolved for seven context elements; the method of accident case analysis was illustrated based on the description of accident context; the mechanism of accident causation was summarized from the accident case analysis; the ontology model of accident cause was constructed to describe the mechanism of accident causation; the risk inter-relation rules were inferred based on the ontology model which described different patterns of risk inter-relation.

The future work will focus on the automatic reasoning for the inter-relation rules and construct the knowledge base of accident cause. It will aim to realize the self-learning of knowledge base by obtaining the new inter-relation rules, then knowledge base will be updating and revising for the knowledge of accident cause. The self-learning of knowledge base will provide a foundation of intelligent risk prevention and risk early warning.

ACKNOWLEDGMENTS

We thank all authors for their work on this paper. We thank conference chair and local committee members, and volunteers for their hard work and contributions to the ISCRAM conference.

The work is supported by the project of National Natural Science Foundation of China (No. 51278030).

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What about IT? Crisis Exercises for Multiple Skills

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ABSTRACT

Cooperation and interaction demands digital skills. In an agile context, there is no time for learning while doing, implicating that many of the skills need to be practiced beforehand. Since exercises are one way of enhancing skills needed in crisis situations, it is important to know what skills are practiced during the exercises. This review aims to understand what skills have been practiced during exercises conducted in Sweden between 2010 and 2014. Data was obtained from 15 evaluations of exercises including multiple actors. Most exercises practiced collaboration, communication, information and shared situation awareness skills. Results showed that 4 out of 15 had a specific goal in terms of technology use. Exercises with explicit technology goals are effective as a way to change opinions about the tool in question. The participants requests additional exercises specifically targeting routines and the use of technological tools.

Keywords

crisis exercise, information and communication technology, IT-practice, skills

INTRODUCTION

During a crisis, all actors dealing with the situation need an information overview to be able to assess and act, and to find a way to handle and cope the situation with whatever is at hand. This is similar to Alberts´s (2011 p. 190) definition of agility: "*the ability to successfully effect, cope with, and/or exploit changes in circumstances*". As a means of preparation, exercises are used to train actors and thereby prepare them to use their skills in unknown situations. Since technology has become omnipresent in a way it never was before, communication and interaction using technology have become natural parts of life. Officials, being highly effected by digitalization, are in need of organizing work for continuous learning (SOU 2015:28). Digital competence has been one of the EU key competences since 2006, with a recommendation to provide adults the opportunity to develop and update key skills through lifelong learning (EU 2006). In 2010, the EU was aiming to enhance the quality of work and to provide better working conditions, in addition to providing people with the right skills (EU 2010). Sweden has set the goal to "develop into the world's most successful digital society" (Hatt 2011).

This makes acting with technology an important skill to be able to handle situations that are agile by nature, such as a crisis situation. According to Turoff (2002), the use of technology in action is dependent on daily use. He claims that if a system is not used on a regular basis it will not be used in an actual emergency. This corresponds well with what Vogel and Schwabe (2016) argue, that stress makes individuals behave according to habit to a greater extent. The problem with using certain systems or tools in crisis situations only is also highlighted in the evaluation of the Västmanland forest fire in 2014 (Asp et al. 2015). The evaluation showed a lack of knowledge of how to use the support systems for communication and information (MSB 2016a). Problems in handling both information and communication technology available to the workers were found, which lead to deciding to not use the systems at all (MSB 2015). This was also the case in the event in Rosengård, where the evaluation concluded that the users had had little practice using the information system, since it was only used in the event of a crisis (Borell and Eriksson 2008).

MSB (2015) also found that during the forest fire they had problems combining actors in the communication system (RAKEL[1]); there was confusion as to which communication group to use. Login to the web based information system (WIS[2]), available to authorities during crisis, was initially problematic since none of the individuals at the incident site had the user information necessary. The system for management and monitoring of rescue (LUPP[3]) was not used consistently from the start, which led to the decision not to use the system at all (MSB, 2015). Asp et al. (2015) claim that in the midst of crisis there is no time to learn how to use special communication and information systems. A stressful environment is not only time-strained, but also affects our ability to learn and impairs memory retrieval (Vogel and Schwabe 2016). The evaluation of the Västmanland forest fire found that it was necessary to strengthen their ability to cooperate, manage and communicate; to develop and use methods and tools as well as increase actors' competence and knowledge (MSB 2016a).

Crisis exercises are executed in order to prepare actors to be able to handle a crisis situation, that is, to be able to use different skills in a time-strained and stressful environment. The effect of stress can be alleviated if learning and retrieval context match (Schwabe and Wolf 2009), which makes the learning environment of exercises important. Lave and Wenger (2005) argue that learning is done within a specific context, a "community of practice". There is a need for a holistic approach when focusing on experiences with IT (Agarwal and Karahanna 2000). Similarly, Orlikowski and Iacono (2001) argue that IT artefacts should not be recognized as merely technical objects since they are tools for work and communication in a social context. Separating technology and people makes us lose sight of the mutual constitution (Orlikowski 2007). How we interact with technology is determined by the technological frames of each individual. Frames consisting of how the individual understands and imagines the technology, how they view the organization's technological strategy and their understanding of how to use the technology. These frames are shared by individuals with the same type of interaction with the technology (Orlikowski and Gash 1994).

Understood in this way, training and exercises that involve numerous skills is of importance to prepare society for crisis situations. Since experience from actual events shows that interacting with technology can be a problem, the question of what skills are being trained during crisis exercises arises. Do the exercises train the skills needed? The aim of this review is to understand what skills have been in focus during exercises conducted in Sweden between 2010 and 2014. If ICT has been a part of the skills practiced during the exercises, experience from the exercises will be highlighted. The result will be presented by firstly providing a picture of research done where crisis exercises and IT have been combined in different ways. The following section will explain the context of this work followed by a brief design statement. The result section provides a description of skills that are frequently trained during the exercises, which illustrate experiences concerning technological issues adjacent to these skills. Finally, the results are discussed, followed by conclusions and ideas for further research.

Related research

When searching for related work, different approaches to crisis exercises in relation to information and communication technology (ICT) emerge. Studies about team exercises (Koning et al. 2012; Mendonça et al. 2006), multidisciplinary field exercises (Rudinsky and Hvannberg 2013), and support systems for crisis management groups (Drozdova et al. 2013) were found. There were also studies on exercises performed in a distributed way (Bacon et al. 2012; Coppari et al. 2008; van de Ven et al. 2014), as table-top exercises (Araz et al. 2010; Edzén 2014), and exercises conducted using a portable IT environment (Bacon et al. 2012). Reuter et al. (2009) focus on software used for planning, and Cesta et al. (2014) study software used to create timelines in scenarios. There are also some studies on the creation of scenarios (Borglund and Öberg 2014; Lundberg et al. 2012; Pottenbaum et al. 2014; Walker et al. 2011). In research on IT in relation to implementation of crisis exercises, it is clear that there is a number of software systems under construction (Ahmad et al. 2012; Greitzer et al. 2007; Oulhaci et al. 2013; Tecuci et al. 2007; van de Ven et al. 2014). Coppari et al. (2008) are developing a learning management system aimed at engineers. A large part of the literature is about computer supported simulation (see e.g. Hawe et al. 2012; LeRoy Heinrichs et al. 2008; MacKinnon and Bacon 2012; Mendonça et al. 2014; Simic 2012; Sniezek et al. 2002; Toups et al. 2011; Van den Broeck et al. 2011) and serious gaming (see e.g. De Kleermacker and Arents 2012; Di Loreto et al. 2012; Greitzer et al. 2007; Mawas and Cahier 2013; Oulhaci et al. 2013; Toups et al. 2011). Jain and McLean (2008) argue that simulation and gaming should be combined to create an arena for multiple agents to practice together. Pottenbaum (2014) emphasizes the importance of logs for learning and debriefing, as do Turoff et al. (2004), as a means to analyze chains of events.

[1] The Swedish national digital communications system used by emergency services and others in the field of public safety (www.msb.se).

[2] Internet-based information system for entities in the Swedish emergency management structure (www.msb.se).

[3] System for operational support for emergency management (www.msb.se).

Research context

In 2002 the Swedish Parliament set up a new crisis management system, aiming for a holistic approach to planning and management of everything from everyday accidents to crisis and war (Prop.2001/02:158). The Swedish crisis management system is based on a bottom-up approach (Prop.2001/02:158). This makes the municipalities the basis of the Swedish emergency management system. Municipalities and other authorities are expected to educate and train officials and municipal staff in order to prepare them for extraordinary events (SFS 2006:544). Municipalities also have a geographical area responsibility, which means that during a crisis the municipality is responsible for liaison and coordination of the activities within the municipality (SFS 2006:544). In close cooperation with municipalities and other authorities, the Swedish Civil Contingencies Agency (MSB) is responsible for measures being taken before, during and after an emergency or crisis in issues concerning civil protection, public safety, emergency management and civil defense. MSB is liable to regulation, supervision and has its own operations as well as support, training and exercises (MSB 2016b). MSB is also responsible for national information and communication systems like WIS and RAKEL, created to facilitate information sharing. This review focuses on exercises where MSB has been involved as funder and support for the planning of the exercise.

Research design

The inclusion criteria for the review were that exercises had to: be conducted in Sweden between 2010 and 2014. Each exercise had to include multi-agencies and have elements of cooperation between these agencies. The exercise must have been evaluated and an evaluation report needs to be available on the MSB website. A total of 15 evaluations were included in the review, see Table 1. As shown in Table 1, 8 of the 15 exercises included pre-seminars. The purpose of the pre-seminars was to enhance knowledge, primarily within the area of the design of the exercise, but also to enhance knowledge of systems like WIS and/or RAKEL. In some cases, exercises included post seminars, aiming to further develop knowledge gained during the exercise.

Exercise	Year	No. agencies	No. individuals	Across national borders	Pre-seminar(s)	Exercise	Post seminar(s)	Evaluation seminar
Amalia	2010	18	403	no	2	1	no	1
Katarina	2010	17	426	no	no	1	no	1
Mårten	2010	29	110	no	no	2	no	1
Sälen	2010	30	139	yes	no	1	no	1
Jenny	2011	15	99	no	2*	1	no	2
Sievert	2011	9	24	no	no	1	no	no
Storskred	2011	19	153	no	2	1	1	1
Torne älv	2011	7	24	yes**	2	1+2+1[z]	no	no
Henning	2012	14	246	no	no	1	1	1
Vendela	2012	12	148	no	no	4+1[zz]	1	no
Astrid	2013	16	270	no	2	1	no	1
Omfall	2013	7	>100	no	3	2	no	1
Pumpa Läns	2013	18	429	no	2	3	no	1
Vildälv	2013	23	450	no	1	1	no	1
Origo	2014	13	Not reported	no	no	1	no	1

Table 1 Evaluations included in the review

** Participants were also encouraged to take an interactive online course on how to use Rakel.*

*** Participants from two countries participated in the pre-seminars.*

z One assignment was given one week prior to the two main exercises, followed by one assignment one week after the exercise.

zz Four assignments were given, one per week prior to the exercise.

In the review of the evaluations a qualitative approach was combined with a thematic text analysis method. The first step of the analysis was reading each of the evaluations a repeated number of times to get an overview. When reading the evaluations it became clear that four areas were common to all exercises, i.e. the skills specified both explicitly and implicitly as the aims of the exercises. In addition, they were frequently used as a way to structure the evaluations. The skills that emerged as common in the evaluations were: cooperation, communication, information, and creating shared situation awareness (SSA). Bearing these skills in mind, the evaluations were again read through a repeated number of times, in search for references to the skills and use of technology.

The review is limited by the use of secondary data. Each evaluation used is has a goal that is different from that of this review. Even so, the evaluations describe the purpose and goals aimed for in each of the exercises. They outline what has been trained, in what way, and the opinions of the participants. The reliability of the evaluations should be considered high since they have been guided and produced by or with the support of the MSB.

RESULT

This section is structured according to the skills that were found during the analysis of the material: cooperation, communication, information, and creating shared situation awareness (SSA). To be able to reach SSA there is a need for both information and communication. Nonetheless, this section uses the areas to structure the result since they are distinctions used in the evaluations.

The exercises included all demand cooperation between multiple agencies. The design of the exercises differs from full-scale and table top exercises with dam failure/flooding or nuclear accident scenarios, see Table 2.

Exercise design		**Exercise (year)**	**Scenario**
Table top		Sievert (2011)	Nuclear accident
Full scale		Amalia (2010)	Plane accident
		Omfall (2013)	Nuclear accident
Seminary	Without counter play	Jenny (2011)	Power failure
		Vendela (2012)	Power failure
	With counter play	Mårten (2010)	Nuclear accident
		Torne älv (2011) **	Flooding
Simulation	Without counter play	Sälen (2010)	Traffic accident
		Storskred (2011)	Dam failure
	With counter play	Katrina (2010)	Flooding
		Henning (2012)	Nuclear accident
		Astrid (2013)**	CBRNE* accident
		Pumpa Läns (2013)**	Flooding
		Vildälv (2013) **	Dam failure
		Origo (2014)	Building construction accident

Table 2 Exercise design and scenarios

** CBRNE, chemical, biological, radiological, nuclear and explosion*

** Exercises with a specific goal connected to technical issues

An additional aim in one of the exercises was to make sure that flaws found in previous exercises were rectified (Brobakken et al. 2010). Four of the fifteen exercises had a specific aim regarding technical issues (Bengtsson 2011a, 2013a; b; Nordin 2013). The aims connected to technical issues were similar. To understand and be able to use layers in GIS was the goal of one of the four exercises. Three of the exercises aimed to use WIS for communication and the fourth exercise aimed to use RAKEL for communication. There are examples of exercises taking steps to improve technological skills prior to the exercise (Bengtsson 2011a, 2012a); there are also examples of evaluations where technology is never mentioned (Länsstyrelsen Västernorrland 2011). These are, however, exceptions; technology is mostly mentioned, at least in passing. The overall aim and goals of the exercises tend to be cooperation (Bengtsson 2010, 2011b; c; a, 2012a, 2013a; b; Myndigheten för samhällsskydd och beredskap 2013; Nordin 2013), how to handle information (Bengtsson 2010, 2011c; a, 2012b; a; Nordin 2013), communication (Bengtsson 2010, 2011a, 2012c, b; a, 2013a; b; Myndigheten för samhällsskydd och beredskap 2013; Nordin 2013), SSA (Bengtsson 2010, 2011c, 2012c; b, 2013a; b; Göransson 2014; Nordin 2013), trying out alarm plans (Bengtsson 2010, 2011b, 2012c, 2013a; b; Nordin 2013), evaluate and develop the organization's ability to handle a crisis situation (Bengtsson 2010, 2011a, 2012b; Göransson 2014), and to increase overall knowledge about a specific area and surrounding agencies (Myndigheten för samhällsskydd och beredskap 2013).

Cooperation

The process of planning seemed to be productive in a number of ways; to the design of the exercise as well as a basis for further collaboration following the exercise (Bengtsson 2010), and has also increased knowledge of surrounding actors (Bengtsson 2010).

There have been discussions about what issues require cooperation (Bengtsson 2010), routines for cooperation (Bengtsson 2010, 2011c), and who is responsible for the initiation of cooperation (Bengtsson 2010). During the exercise Sälen (Brobakken et al. 2010), it was established that knowledge of other actors as well as established ways of contact are crucial for efficient cooperation. Structure and who is responsible for leading the cooperation meetings were also topics discussed (Bengtsson 2010). Needs for clarification and cooperation routines were identified (Bengtsson 2010, 2011c; Nordin 2013), as some of the meetings were perceived as unstructured (Bengtsson 2013a). It was suggested that agendas were prepared to be used in these situations, since structure is important when time is short. Leadership during collaboration meetings was also identified as important, and it was suggested that it should be decided in advance who is going to lead the meeting (Bengtsson 2010).

There is also need for technology to back this up. Videoconference is highlighted as a good solution, but regardless of technological solution the participants have to be prepared for the meeting. The solutions also need to be tested beforehand and allow simple things like muting the microphone (Bengtsson 2010). When cross-border cooperation is needed, problems occurred where contact channels affected information sharing between countries (Brobakken et al. 2010). Conference call is also used, but the evaluation does not mention how the participants perceived this (Bengtsson 2012b). A need to increase and improve the use of RAKEL communication was detected, primarily because it is not used in everyday work (Bengtsson 2012b). For example, when consciously using RAKEL during the exercise, the participants had a noticeable change of opinion about the system in a positive direction (Bengtsson 2012a).

Communication

Communication in locations where there are shadow zones can be a problem (Bengtsson 2010). Another problem that occurred during the exercise in terms of communication was participants using other means of contact than those agreed on. Private cellphones and calls from spare vehicles resulted in a chaotic situation at SOS[4] and at the command center of some of the participants (Bengtsson 2010).

It is important to understand what issues are important to communicate. A description of these issues could be useful, since an actual accident involves added pressure for the operator (Bengtsson 2010). Some participants perceived the communication of information as irregular and far apart (Bengtsson 2010).

For some, using RAKEL for communication was an entirely new experience, which explains their being unaccustomed to using the system. Some argued that instead of using cellphones RAKEL should be used, to be

[4] The Swedish national organization for emergency calls

able to spread the information as far as possible (Bengtsson 2010). But since some still do not have access to the system it leads to a need for routines for how to reach those without access to RAKEL (Bengtsson 2013a).

Information

Sometimes meetings during the planning stage were conducted in an informal setting, which resulted in information loss as decisions from short conference calls were never communicated outside the small group present, or interested parties outside the organization (Bengtsson 2010, 2011b). Much of the documentation during the planning was sent by e-mail between participants (Bengtsson 2011b). Despite this, more documentation from planning meetings was requested (Bengtsson 2012a), as was documentation from decisions during the exercise (Bengtsson 2010, 2011c, 2012b, 2013a, a; a; Nordin 2013). Various systems are used for documentation, but there is no discussion about in what way or if this results in any problems (Bengtsson 2012b). Routines for documentation were asked for during the exercises (Bengtsson 2012b, 2013a). For example, there was no routine for whiteboard and scratch paper documentation, or how to document e-mails (Bengtsson 2012b). One of the evaluators interfered mid-exercise and suggested that WIS could be used as documentation channel (Bengtsson 2013b; a). One participant conducted all communication through a third party to avoid documentation. This requires the ability to listen-in on calls in order to not lose valuable time for analysis (Bengtsson 2010).

Clear documentation is perceived as important. Preferably a template is used to make it as clear as possible (Bengtsson 2010). A structure for documentation in WIS is requested (Bengtsson 2011c). Participants that had assigned documentation and information to one member of staff argued that this was a good way to organize the work. The organization felt that their information work was successful (Bengtsson 2010). A conclusion drawn by the participants, was that the communication between different documentation systems should be done automatically (Bengtsson 2010).

WIS is both mentioned as a way to facilitate and support the collection and sharing of information (Bengtsson 2013c) as well as a part of the exercise goals (Bengtsson 2013a). Participants found that it is hard to use a system that was only used during crisis or exercises. Systems need to be used in other situations than during an exercise (Bengtsson 2012a) both for users to know how to use the software and to learn how to use it better (Bengtsson 2011c), it is clear instructions and routines are required (Bengtsson 2013a). Participants mention that they would like to have both training and education on how to use WIS (Bengtsson 2011b, 2012c, 2013b; a; Nordin 2013) and RAKEL (Bengtsson 2012c, 2013a). The absence of technology use is observed even though there are digital devices in the room that could facilitate the work (Bengtsson 2013b). Some participants also lacked access to update information on the platform used (Bengtsson 2010). According to the evaluation, there was a lack of guidelines for which presentation tools to use, and decisions on where to present the information were made at random (Bengtsson 2010).

The participants requested procedures and routines for how to create and distribute coordinated information (Nordin 2013). The importance of choosing which channel to use for information sharing and gathering is noted (Bengtsson 2010, 2011c). There were discussions about what information should be delivered, and if there is a risk of information overload (Bengtsson 2010). A frequently used channel for gathering information was the radio (Bengtsson 2010). When it came to sharing information, a lack of coordination and collaboration was observed. Some of the participants did not have access to WIS (Bengtsson 2012a), and some chose not to use it (Bengtsson 2010, 2012c), which made it unclear how many were reached by the information in the system. In cases when participants had access to WIS, not all of the participants chose to share their journals and to make their information available to other participants in the exercise. However, not all participants followed the journals shared by other participants. (Bengtsson 2011c). There was limited use of the intranet to distribute internal information, which was identified as a point of improvement (Bengtsson 2010). Ideas for what channels to use for internal information was also a result of the exercise. Another point of improvement was guidelines for what to communicate, how to structure it, and the amount of information delivered through social media and websites (Bengtsson 2010). There are discussions about what channels to use to distribute information to the public, and how to adapt the information to different target groups but no discussion about the effect of different channels (Bengtsson 2012a).

Some exercises confirm that actors use both WIS and personal technological systems to share and present information (Bengtsson 2010, 2012b), but there is no mention of their skills in handling the systems (Bengtsson 2012b). One evaluator notes that a problem is that the different systems cannot communicate with each other (Bengtsson 2012b). Some information sent between participants was not read because of compatibility issues (Bengtsson 2012b). The need to regularly update the information presented was also highlighted (Bengtsson 2012b). Some participants in the exercises in 2011 emphasize the importance of being able to visualize information which provides a clear picture of the situation (Bengtsson 2012b; a). There were participants with technology well-suited for the visualization of the event, which could, in theory, be shared with other participants, but because of security solutions and software issues it was impossible in practice (Bengtsson 2012b). Some participants lacked the physical localization suitable to visualize the event, which results in problems viewing past, present and future information of the event. Others struggled with the structure and procedure of what information to display, leading to a lot of static information (Bengtsson 2010). When reporting about the situation at the scene, information was at times insufficient and unstructured, and not always delivered on time, and sometimes not at all. This affects the support given to participants at the site of the incident (Bengtsson 2010). There is a need for guidelines for these reports (Bengtsson 2011c).

Shared situation awareness (SSA)

Some participants used monitors to visualize the SSA. They also included pictures sent from the location to get the clearest picture possible (Bengtsson 2010). However, not all participants considered this as something positive, since the monitors could be a distraction once the briefing was done (Bengtsson 2010). There were also cases where the SSA was shared orally (Bengtsson 2013b).

Some evaluations are clear about what technology is involved in the display of the SSA and reflect on the effect of having an oral presentation of the picture only (Bengtsson 2013a). Routines and procedures for how to create the SSA (Nordin 2013) are requested, as are routines for the creation and visualization of an SSA in a transparent way, in addition to a clarification of the difference between situational awareness and documentation (Göransson 2014).

Participants requested better procedures and structure for the SSA, how to display the SSA and what it should consist of. The SSA is sometimes perceived as more of a duty rather than something useful when handling the situation, which leads to working with the SSA only when it is to be presented at meetings with other actors (Nordin 2013). The participants do not see the importance of sharing, creating and having awareness of the bigger picture. Instead they feel it is enough to have knowledge of the parts they need to solve the situation within the area of their responsibility. There are indications that participants do not seek and verify information, which leads to situation awareness relying on external information and no attempts made to verify the SSA (Bengtsson 2012b).

Discussion

To be able to handle an agile situation like a crisis, most probably in a stressful environment, demands a vast set of skills. Stress impairs memory retrieval and make people behave according to habit to a greater extent (Vogel and Schwabe 2016), but the effect of stress can be alleviated if learning and retrieval context match (Schwabe and Wolf 2009). This argues for the importance of exercises and training as a preparation for the unexpected. As digital tools are frequently used in day-to-day work and various events showed that some choose to not use these tools, finding out what skills are being trained during exercises could be useful. The aim of this review was to understand what skills were practiced during the exercises, and if ICT was a part of the skills practiced, as well as to illustrate experiences drawn.

The review finds that the most frequently practiced skills are cooperation, communication, information sharing, and creating shared situation awareness. During the exercises, technology was not always a natural part of what was practiced. Instead technology was not used at all, or was taken for granted while other objectives were in focus. The skills identified are all areas that involve technology in one way or another. Participants express a need and wish to learn how to use technology more efficiently (Bengtsson 2011b, 2012b; Göransson 2014; Nordin 2013), since technology is considered to be useful, but demands that the staff knows how to use it (Bengtsson 2011c). Experiences from the exercises highlight the need to improve technological skills, regardless of whether the goal of the exercise was explicitly technological or not. When pre-seminars were used to prepare participants on how to use for example WIS, the outcome of the exercise tended to be positive. Both because it seems to increase the participants' level of satisfaction with the exercise, and because having the time to prepare was considered necessary. In addition it was also an effective way of changing how the tool in question was perceived. There is no plan as to what tool to use to display different types of information. This leads to users having to make these decisions then and there. According to Vogel and Schwabe (2016) stress makes individuals act according to habit to a greater extent. That is, when under pressure, people tend to choose a tool s/he is familiar with without taking into consideration if there is another tool that could be more suitable.

In these exercises, participants have mentioned wanting a clearer structure for how to use WIS for documentation, guides, routines and guidelines. Agarwal and Karahanna (2000) argue that a holistic approach focusing on IT experiences is needed. In the exercises, participants from exercises, regardless of whether the exercises have goals that are explicitly technological or not, have mentioned problems using the tools and described the effect of using certain tools. This is similar to what Orlikowski argues, that separating technology and people make us lose sight of the mutual constitution (Orlikowski 2007). Participants in the 4 exercises with explicitly technological goals mentioned wanting clearer routines and procedures for how to use and present information using the tools. During the exercises, practical issues of how to refine routines and develop skills using the technical device were identified. Participants in all types of exercises requested more training and practice using the technology involved in the handling of the crisis, indicating that there is a need for training to facilitate the use of the technology in their job.

Creating a shared situation awareness (SSA) both within an organization and across multiple organizations requires routines, procedures and structure, which was something all actors involved requested. When creating SSA using technology, technological frames are set (Orlikowski and Gash 1994). A carefully designed crisis exercise will enhance multiple skills including the digital skills needed to solve an assignment. Using technology but not following up on the results of using said technology is in itself a risk. In the exercises, participants were told to use a specific information system, however, not all of them did, and there were some who did not know how to use it. The evaluations do not discuss the impact of this on the construction of the SSA and solving the issue at hand. This shows the importance of considering the practice, including IT, not only during the construction and implementation of exercises but also the during the evaluation phase of exercises, in order to find issues in the use of IT. Evaluation of exercises where the use of certain technology is a goal captures technical issues more clearly and illustrates areas of improvement, but also the effect of using, or not using, technology.

Conclusion

Even though technology is a natural part of everyday life for many people, those participating in these crisis exercises have been struggling with both demands based on the crisis scenario and a lack of routines as well as lack of technological strategy and insufficient digital skills. Finding the time to develop the skills needed in a crisis situation is difficult, which makes it important to make the most out of any exercise taking place. A crisis exercise is a context that can be used as an opportunity to learn more than isolated abilities like communication in a crisis context; it can be used to further develop digital skills which will benefit the organization. Experiences from the exercises as well as previous research (see e.g. Asp et al. 2015; Borell and Eriksson 2008; Turoff 2002) shows that how technology is used in a crisis depends on its use on a daily basis. One way to use technology intended for the use in a crisis situation and enhance knowledge could be to use these technologies in the planning phase and thereby creating an opportunity to use a tool rarely used.

The results of this paper should be of interest for scenario makers. When creating scenarios, including digital skills in the exercise should be considered. It could be things such as making sure that people have access to the necessary systems and restricted rooms, or including, for example, finding the right position on a map using GPS and/or coordinates in the exercise. Experience from these evaluations shows that pre-seminars preparing participants by giving them training and practice using the technological systems used in the exercise have been successful. Participants have also mentioned that there is an uncertainty about how to handle technological tools.

In the evaluation, participants requested routines, structure and training in technological skills. A problem that seems to emerge when looking at the evaluations, is that requests and flaws found early on, and many years ago, are still requests and flaws in exercises carried out in 2014. This leads to questions of how to transfer knowledge from one exercise to another. There is a need for research aiming to understand how experience from both actual crisis as well as earlier exercises can be used to develop future exercises, and how these experiences can serve as a source of knowledge in the event of a crisis. The way exercises are evaluated is also an area for research in order to find new and complementary ways to evaluate exercises. There seems to be a lack of research that aims to understand the entanglements of technology and actors during a crisis situation. This is of essence if exercises that aim to reflect the actual practice. Participants expressed uncertainty concerning how to handle technological tools. It would be of interest to study to what extent involving technology experts in the exercises, for instance participants from the IT department, would affect the degree of use and perceived confidence of handling technology. There is also a need for research studying different approaches to exercises in order to understand how preparation training and layout of the exercise affects the outcome and how exercises are perceived.

This work was supported by the Interreg Sweden-Norway program [20200037]

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Co-creating Communication Approaches for Resilient Cities in Europe: the Case of the EU Project Smart Mature Resilience

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ABSTRACT

Cities face a wide range of risks. Potential threats range from natural disasters and the (relatively slow) environmental change, to man-made issues like extremism. To overcome such threats, cities ought to be resilient, capable of resisting problems, of adapting to new situations, and overcoming crises. Effective communication is particularly crucial for a resilient city. Rather than trusting that relevant stakeholders, municipal staff and citizens will intuitively communicate in the ideal way, cities should see communication as a strategic aspect of their resilience development. Thus, how resilient cities communicate should be strategically managed. In this paper, we present immediate results from an ongoing European project called Smart Mature Resilience. In this project, we work with seven cities towards the ultimate goal of developing a Resilience Management Guideline for all European cities. Moreover, we intend to set up a resilience backbone in Europe, which will be driven by effective communication between cities.

Keywords

Resilience, cities, co-creation, communication, information

INTRODUCTION

Cities across Europe are facing complex environmental, social and economic challenges as well as an increasing frequency and intensity of hazards and disasters. Studies on risk in cities by the Cambridge Centre for Risk Studies have demonstrated that "we live in a world where crises can, and do, occur from a wide range of potential causes, many of them unexpected." (Coburn et al, 2015). Evidence indicates that exposure of persons and assets in all countries has increased faster than vulnerability has decreased, thus generating new risks and a steady rise in disaster-related losses, with a significant economic, social, health, cultural and environmental impact in the short, medium and long term, especially at the local and community levels (UNISDR, 2015). These challenges are closely linked to climate change and social dynamics, whether as causes or aggravating factors.

Resilience is defined as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." (UNISDR, 2009). Communication is one of major streams in building resilience (Horne, 1998). A city's coping capacity depends on clear channels of communication between relevant actors, in addition to a responsive and well-structured emergency response system and effective social infrastructures (Johnson and Blackburn, 2014). Ineffective communication has been cited as a factor in the failed response to natural disasters including flood events in the UK and flooding resulting from Hurricane Katrina (O'Sullivan et al., 2012). Reducing vulnerability requires functional communication infrastructure in cities and effective internal communication within the city administration and between the municipality and its most crucial stakeholders: for example, first responders in the case of crises, and with citizens during daily operations. Communication with citizens is essential to the engagement and empowerment of citizens that provides the foundation for socially resilient communities.

This research-in-progress paper addresses the process of co-creating communication approaches for resilient cities. Co-creation is an effective method to address the above-mentioned communication-related challenges, as it ensures that communication approaches and tools are developed specifically for the needs of cities and are closely tuned to the actual communication practices in place in cities. Further, we describe the development of a communication tool that can facilitate the strategic communication necessary for resilient cities. We propose that this kind of tool or the strategic communication necessary is described is necessary for resilience, as communication exclusively in terms of crisis situations is insufficient. The tool was developed in response to the call by project cities for holistic and integrated communication that accounts for communication during daily work as well as during disasters while the other ongoing research projects and existing tools focus mainly on disaster responses. This tool and the project's investigation and testing of communication methods attempts to address the gap identified by Turoff et al. that "what is truly missing is to look at what could be done to design for this [social media] trend and integrate it and citizen participation into all the phases of disasters" (Turoff et al., 2013).

This paper reports on the European-funded project Smart Mature Resilience. Smart Mature Resilience responds to the need for enhanced resilience in European cities. A Resilience Management Guideline and a set of practical tools are piloted in a core group of cities and shared with a wider group of cities, with the objecting of strengthening the nexus of Europe's resilient cities overall. Researchers and cities cooperate in a cycle of development, pilot trials and evaluation. Researchers work with the project cities of Donostia/San Sebastian, Glasgow, Kristiansand, Vejle, Riga, Bristol and Rome to co-create and pilot tools which help cities assess their resilience maturity, identify and implement resilience building policies and cooperate with stakeholders. The participating cities are active project partners who contribute to creating the Resilience Management Guideline as well as serving as the test-beds where the project tools are tested.

The paper is structured as follows: (1) description of the tools, (2) co-creation process, (3) communication strategy building process, (4) portal development process, (5) portal implementation plan, and (6) conclusions.

PROJECT TOOLS

As of early 2017, three tools have been developed. The first tool is the Resilience Maturity Model, which identifies the ideal path towards resilience. This model defines five stages of resilience maturity, from an initial stage to a highly advanced stage. Each of these maturity stages has four dimensions: leadership and governance; preparedness; infrastructure and resources; and cooperation, and the model takes into account the practical reality that cities begin their resilience development from a variety of starting-points that often vary across the different dimensions.

The second tool that has been developed is the Resilience Information Portal. This portal serves as a toolbox that can complement and enhance the platforms and software that cities already have in place. It allows cities to display data internally or publicly that is already available to the city as it applies to resilience, vulnerability and crisis situations. The portal allows for different levels of users to allow for city managers, critical infrastructure providers, citizens or other stakeholders to be able to contribute information as applies to a given city context. The portal offers added value not available to cities (as they self-reported), as the cities have multiple (and in Glasgow's case, dozens) of platforms in place in their municipalities for internal communication, but the wealth of information available to them is not integrated, streamlined or fully utilized. Furthermore, the tool includes a number of levels of users, which accounts for the complexity of the network of stakeholders and target groups that are to be considered in building resilience. Lastly, the toolbox format facilitates the practical reality in cities, which is that replacing existing communication systems is impractical and would cause unwarranted disruption. Therefore, providing the platform as a toolbox allows cities to select the elements not already available to them without undoing or disrupting facilities and channels that already function effectively.

A Risk Systemicity Questionnaire has undergone pilot testing and is being finalized at the time of writing. This is an interactive worksheet where users can self-assess risk in their own city as well as their awareness of risk in their own city by considering the relative likelihood of vicious cycle scenarios in terms of health, climate change (air pollution), climate change (flooding), social inequalities, ageing (population), riots, immigration, social cohesion and social alienation. The project is currently developing the final two tools, a portfolio of resilience building policies and a system dynamics model. The five tools will, in combination, comprise the European Resilience Management Guideline.

CITIES AS CO-CREATORS

The project tools have been developed in a process of pilot testing and feedback gathering with the cities in order to ensure that the tools cater closely to the cities' needs. This feedback process also places the project research under constant 'reality check' scrutiny. Collaboration with the cities has made evident that each step of the resilience-building process requires strategic communication, and that a communication strategy is a crucial element of resilience development.

The involvement of cities as project partners has meant that those contributing feedback and data to the development of project tools has been individuals working on the project as part of their daily work in resilience, planning, environmental, crisis management and other departments of their respective city councils and municipalities. Additionally, depending on the nature of the tool or the type of feedback needed, city partners have involved stakeholders from across the municipality and the municipality's network including citizens, reflecting the extremely broad reach of the field of crisis management, and even broader reach of resilience management.

As mentioned already, the three main partner cities, Kristiansand, Glasgow and San Sebastian have been the early adopters and present the operational environment in which the pilot implementation of the Resilience Information Portal took place. During this process, a core circle of city representatives, plus some additional, relevant stakeholders have provided with valuable input that led into the finalization of the tool. The remaining four partner cities, which have not been serving as pilot implementation cases (Vejle, Bristol, Rome, and Riga) were involved in the implementation and review process, assuming the role of peer-reviewers. More particularly, they were assigned with an observer role in the pilot process, monitoring the progress of the core cities and providing feedback and insights, which aimed to ensure that the final portal, with its specific qualities and functionalities would be widely replicable and applicable to other cities in Europe; cities that will form the so-called European Resilience Backbone. The core cities and their local research partner worked closely together on co-creating and testing the portal, with a particular focus each case on building resilience against risks that fall within each chosen security sector.

Citizens are "inherently creative and want to shape their own experiences." Co-creation is a way that cities can tap into that creativity while providing all stakeholders with a feeling of control over something within the process (Fuchs et al 2016). Throughout the project's co-creation process the cities were always encouraged to further engage with the stakeholders in creating and increasing the value of the portal for strengthening the communication flows in bottom-up, top-down and across-silo streams and therefore enhancing each city's resilience.

Turner (1967) makes use of a 1932 definition of disasters, where "a catastrophic change is a change in the functional adequacy of certain cultural artefacts." While our project reaches much more broadly than only dealing with crisis situations, the objective of avoiding, mitigating and recovering from the effects of extreme events nonetheless informs the communication practices we will propose in this paper. Further, the project's city partners contributed numerous examples in terms of critical infrastructure where disasters and accidents were a trigger provoking the implementation of policies or gaining political recognition for the implementation of resilience-related policies. A disaster or cultural collapse takes place because of some inaccuracy or inadequacy in the accepted norms and beliefs (Turner, 1967). Following the data gathered from the Smart Mature Resilience cities, one of the ways in which cities both respond to disasters and assuage unrest among citizens following disasters is by implementing policies related to critical infrastructure protection, risk management, climate change adaptation, preparedness and resilience. The events functioned as triggers to spur institutions to implement resilience-related policies. The following examples were gathered at a project workshop and are detailed in the Smart Mature Resilience report, Critical Infrastructure Dependencies Workshop Report (Gimenez et al., 2016).

For example, Bristol's power and water supply were affected by flooding in 2007, which led to the introduction of new flood and water management legislation in 2010, which empower city councils and local coordinators to make more decisions regarding flooding. In 1999, a heavy storm in Vejle caused a power outage that lasted for four days, causing manufacturing to grind to a halt for several businesses. This event led to companies planning alternative emergency supply generators for crisis situations, and also fostered networking and information sharing among electricity suppliers. Donostia's communication system was affected by flooding in 2007, incapacitating emergency services during the peak of the crisis. This led to the improvement of emergency services and alarm warnings that capitalise on neighbourhood outreach via social media. Companies and industries located in flood-prone areas have also been moved to lower-risk areas.

In 1994, Glasgow was affected by flooding that had an economic impact on the city. This disaster led the authorities to think collectively at a strategic level and to develop risk plans to mitigate the flood impacts. Moreover, partnerships were created among private consultancies, private companies, and the Scottish water agency. In 2011, engineering works were developed to prevent flooding and these risk plans have been improved over the last years. As a result of heavy snowfall in Riga during November 2013, the roof of a popular shopping mall collapsed under the accumulated snow, causing the deaths of fifty-seven people. Since this event, the societal awareness of the importance of structural building maintenance increased. A new construction department was also created in charge of analyzing buildings and determining which buildings are no longer fit for use.

These examples demonstrate the close relationship between communication and resilience development. Furthermore, they show that strategies and policies that relate to resilience are implemented in response to crisis situations.

COMMUNICATION STRATEGY BUILDING PROCESS

The Smart Mature Resilience project communicates with the project's target audience and stakeholders according to a communication strategy developed at the outset of the project. All project partners participate in communication and dissemination and all were, as such, involved in the development of the strategy.

The first step in the development of the communication strategy was a situation analysis of the project's communication environment. The major communication-related challenges and risks were identified. Challenges were found to include terminology and conflicting usages of the term 'resilience', data availability and heterogeneous data sources, and the issue of standardization. These challenges have since the project outset been successfully addressed, with the development of a project definition of resilience for the former issue, the careful analysis and interpretation of data in addition to sourcing of data directly from cities, and the project's development of a draft CEN Workshop Agreement towards establishing standards. A CEN Workshop Agreement (CWA) is a document published by CEN in at least one of the CEN three official languages. A CWA is an agreement developed and approved in a CEN Workshop. A CWA does not have the status of a European Standard.

The second step in development of the communication strategy was the establishment of the project's key messages, which are as follows: Cities need to become more resilient; Resilience relies on functioning critical infrastructures and dynamic social interactions; A holistic approach can enhance resilience in Europe; The project develops tools to assess and develop cities' resilience; The project results can advise the decision-making process towards enhanced resilience. Project stakeholders were identified as: cities, encompassing population (general public and local communities), critical infrastructures (city staff and technicians, utilities), media, state-owned enterprises and first responders; the research community; and EU policymakers. Private business was identified as a secondary target group.

The project uses a variety of communication channels in order to reach these target groups. Firstly, internal and external events are a primary communication channel, including project meetings, workshops and webinars, a Stakeholder Dialogue, Stakeholder Workshop and final conference. Next, the project website primarily facilitates external communication and serves to represent the project to an external audience with the widest target group. General project information including public reports, announcement of events, project outlines and related news are be updated regularly. A mailing list is a further communication channel, to which the project newsletter is be distributed via email on a quarterly basis. Subscriptions to the mailing list are available via the project website. The social media platforms of LinkedIn and Twitter are used for networking among city policymakers, city administrative staff and researchers and encourage discussion with the research community and the interested public.

Communication channels available through the project partners were also identified as local television, local radio, local newspapers and partner institutions' communication departments. The communication strategy also dictates a visual identity and guidance for of the project logo and colours, in order to ensure coherent representation of the project across project partners.

Communication target groups and channels were established as follows. A project leaflet was produced summarising the main project information with a target group of cities. Print and electronic articles and press stories with results obtained and activities developed in the project also aim to communicate with cities. The project website, including project progress, results, deliverables and dissemination materials aims to communicate with cities and the general public. Social media posts communicating activities carried out, results obtained and project news is aimed at the general public. Print and electronic articles and publications in scientific journals explaining the research methodologies applied and the results obtained, as well as oral presentations and poster exhibitions at scientific conferences aim to communicate with the scientific community. The project newsletter containing activities carried out, results obtained and project news aims to communicate with a specialised topical audience, cities and multi-level governance. Policy briefs with policy-relevant project results aim to address decision makers and the European policy level. Oral presentations and participation in the standardization workshop to discuss standardization potential within the project as well as a printed CEN Workshop Agreement will reach city representatives and stakeholders involved in the standardization process. The final conference should address all European cities and will also take into account cities from outside Europe.

COMMUNICATION WITH CITIZENS

Smart Mature Resilience has seven cities as active partners; they are responsible for contributing to project communication and are a primary resource for directly communicating with citizens. As part of the project's communication approach, cities were provided with communication support in developing press releases according to a tri-annual timetable to inform citizens of issues relevant to them related to resilience.

The types of press releases to be developed followed three general approaches. Opportunity-based communications relate directly to concrete disasters and emergencies, and contextualize the work the municipality or city council is doing directly to an extreme weather event or other tangible crisis that is current news. This counteracts the challenge of communicating effective disaster response and resilience development, where successful response or high levels of resilience generate less communicable results than poor emergency response or low levels of resilience. The second press approach follows a story-based style, where press releases or articles are related to current affairs or the cultural context of the city. The third approach is commentary on resilience as a topic, which is primarily produced due to deeper topical expertise and access to more specialized communication channels.

COMMUNICATION BETWEEN CITIES

One outcome of the Smart Mature Resilience project is the exchange and communication facilitated between cities. During co-creation and pilot testing of the tools, the cities were in regular contact and provided each other with numerous real examples, strategies, experiences and opinions regarding how resilience management works in their local contexts. The communication strategy of the Smart Mature Resilience project foresees the project cities as multipliers of the tools and outcomes of the project to a wider group of cities, following the successful exchange and collaboration within the project between city partners. The project's objective is to build a group of resilient cities who can support one another and the broader group of cities around the world, as cities must be considered not only to be networks in themselves, but also participants in networks that comprise of and include other cities and their respective sub-networks. Peer exchange and sharing of information is already happening, including in terms of resilience, in many partnerships and groupings between cities globally. One of these active city groupings is ICLEI – Local Governments for Sustainability, which was one of the motivations of involving ICLEI as a partner in the Smart Mature Resilience project.

THE PROJECT WEBSITE AS A COMMUNICATION CHANNEL

The project website is a primary communication channel for the project. It provides information on the project, profiles each project city in terms of resilience, shares news stories and events, hosts all of the project's scientific outputs and tools. The website was designed to feed naturally into the resilience information portal by means of matching website design, so that users can easily access the portal and training material directly from the project website.

PORTAL DEVELOPMENT PROCESS INCLUDING HOW CITIES' INPUT WAS INTEGRATED INTO THE PROCESS

System development is typically described in a sequential, step-wise order. It then roughly follows the waterfall model and distinguishes planning, requirements analysis, system design, implementation (i.e. programming), testing and productive usage (Royce, 1970; Boehm, 1976). The Resilience Information Portal development followed an agile development approach (Sommerville, 2011) as the portal means to reflect the information sharing needs of the cities. It can be built based on the input from the city partners, in particular with feedback from a variety of municipal stakeholders. The portal seeks to be a generalizable solution. Thus, development of the portal needed to be carried out in incremental steps and could lead in some cases to mi-term changes to existing parts. The challenge is that the portal seeks to be a generalizable solution while cities have varying expectations and communicate in differing ways. A high level of heterogeneity is encountered with regard to communication strategies. Thus, while the production of a technological solution is important for a demonstration of feasibility and in order to provide a tangible system to discuss, the underlying processes, concepts, and ideas are the more valuable contributions of the project. The following figure describes the portal development process. It highlights three activities: interviews with cities to gain their insights, portal development and feedback loop. Development was started based on a set of bootstrap portal requirements. Since we can only rely on the literature and on existing approaches yet need to start with initial requirements for the first platform, this bootstrapping is done.

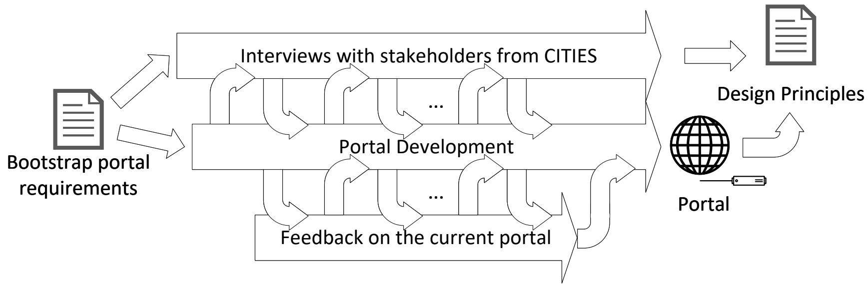

Figure 1. Portal development process

The arrows leading from the development can be read as both providing the next iteration of the portal (or, in the case of the first arrow, of the "naked" platform) and as giving replies about development activities. The latter is necessary as we might realize that some functionality described by the cities is not feasible for implementation or because we come to new ideas in the process of development that we want to discuss. The arrows leading to the development can be read as formal (interview data) or informal (comments, wishes) feedback.

Between January and April 2016, face-to-face interviews were conducted with six cities. Twelve stakeholders took part in the interviews, leading to 20 sets of interviews in which 33 individual interviewees participated. The primary purpose of the interviews was to derive design principles for the Resilience Information Portal. The process of derivation of design principles follows the design theory for dynamic complexity (Hanseth et al. 2010). According to this theory, the identification of design *problems* should come first since it guides us to design *goals* and *principles.* Design principles in this sense refer to the way of achieving design goals. We first set up the pre-questionnaire survey which was provided online to identify communication challenges (design problems) then proceeded to face-to-face interviews. In the pre-questionnaire survey cities were asked the communication activities require using an information system that enhances resilience before identification of the challenges. In this sense, communication challenges identified by each city describe problems towards resilient cities. Based on the results of the pre-questionnaire, the following nineteen communication challenges are identified: lack of integration of communication tools, information fragmentation (including incompatibility of information and systems), logging incident information, presenting information on complex emergencies, lack of updates on what others are doing, lack of direct communication, raising awareness of potential and real threats among the citizens, lack of information variety, unawareness of information reach, contacting relevant people (internal officials) quickly, communicating with "hard to reach" groups (e.g. people who do not speak the local language), human resource updating, lack of interactive communication, long-term involvement, security, information confidentiality, handling of documents marked as protected or confidential, mal-information on social media, and managing social media.

To approach these various challenges, we propose the following six design principles: (1) information sharing, (2) establishing a communication structure with stakeholders, (3) knowledge sharing, (4) citizen engagement and raising awareness, (5) information sovereignty, and (6) usability. The first principle becomes the foundation of the other five principles. It guides HOW the information delivered and WHO should be reached. Communication starts with setting up a physical service centre towards citizens. Platforms (website, social media, internal systems) to share information with stakeholders are implemented. Cities identify target groups to enhance engagement. Target groups are varied like first responders, local communities and social groups and communities of interest. Thereby, the population must be reflected. When the foundation set up, cities establish a communication structure with related stakeholders. They share objectives and issues. Communication at a distance should be supported by the platform as well as face-to-face conversation. The project cities acknowledge (or provide) resource capacity for updating information on certain platforms, responding to inquiries from stakeholders, and on translating information into several languages, The cities expressed the need for a library of best practices to be set up and shared with neighbouring cities, in national networks and in an international consortium.

Among six design principles, we found that citizen engagement and raising awareness is the most critical goal for cities to achieve resilience since they realize it is no longer sufficient to handle complex issues merely with internal resources. They need to mobilize citizens' and stakeholders' capability and create value together. Cities are curious about social media as means to involve citizens. As suggested by Moorhead et al (2013), social media could provide benefits to engage citizens. For deeper understanding of social media's potential, we conducted additional interviews with the four cities out of six using Skype and WebEx. In regards to citizen engagement and empowerment, the literature proposed several ways of doing this, such as participation promotion (Boehm et al. 2004), producing a sense of unity (Zimmerman 2000), and sharing problems and role ownership (Conger et al. 1988). Cities provided a particular case of using social media to engage citizens and they all have been given these benefits. For instance, as explained by the City of Kristiansand, they use a Facebook page to communicate with children and young people, who are otherwise not in regular communication with the city administration. The City of Vejle utilizes multiple social media like Facebook, Twitter, and Instagram. They combine face-to-face dialogue and try to get citizens involved in the future city development. In Bristol, officers use a professional Facebook page to engage 14 neighbourhood partners for decision-making. On their Facebook page, they collect partners' opinions as well as sharing information. This contributes to reducing costs for gathering opinions, as users of social media can be more ready to offer opinions online rather than attending public meetings. Additionally, different target groups can be accessed through social media than would be accessible at public meetings. As reflected in the identification of target groups for communication of the Smart Mature Resilience project, different groups require different channels of communication in order to be effectively reached. Cities realize that strategic two-way communication through a range of channels, including social media, is a prerequisite for resilience-building.

Cities' contributions and examples demonstrated to us the importance of narrative creation. Partners expressed their experience that municipal communication channels enjoy a particularly high-prestige level of trust among citizens. When information is shared online directly by cities, citizens believe for the most part that the information is, even if not complete, accurate and provided for their benefit. City channels also benefit from a high level of attention by the media, have close relationships with local media and information and press releases shared by cities and municipalities are picked up by media as standard. Sharing of trustworthy information also maintains and increases citizens' and stakeholders trust in them. In order to guide citizens or influence their responses to disasters in a strategic way, a coherent narrative is essential both in crisis situations as well as during ordinary daily operations in order to establish a common understanding of risks and roles.

Regular and two-way communication and engagement with citizens during non-crisis times can help to counter the challenge described by Turner (1976) as "Involvement of strangers," whereby crisis management plans fail to account for the reactions and behaviour of individuals from outside of the plan-making institution as "administrators may… run into error in communicating with them because they adopt oversimplified stereotypes when considering their likely behaviour and characteristics." Established relationships and engagement can open the system to include citizens in the communication processes of the city. While not allowing for targeted briefing, as is possible with appointed staff, longer-term communication across a number of media nonetheless allows the city to create a narrative for how citizens should understand their role in the city, how they should ideally react to hazards and prepare them in order to guide their expectations and reactions when crisis situations do occur.

PORTAL PILOT IMPLEMENTATION

The Resilience Information Portal that was created proves that this co-creation process proves is not only useful as an innovation practice, but also as a strategic method to strengthen brand value and positively influence the citizens' perceptions on attempted resilience-building efforts. Furthermore, the Resilience Information Portal was treated and regarded as a collaborative environment to facilitate awareness and engagement among key partners in resilience building activities. The portal particularly serves two purposes:

- Support communication within the city, between the city and its stakeholders, and between the city and its citizens. In addition, the integration of social networking services is supported.
- Enable knowledge sharing as a long-term communication activity. Similarly to short-term communication support, the city, its stakeholder, and citizens are included.

The Resilience Information Portal demonstrates that co-creation is not only useful as an innovation practice, but also as a strategic method to strengthen brand value and positively influence the citizens' perceptions on attempted resilience-building efforts.

After the first weeks of the pilot implementation process, a series of webinars was also conducted aiming to support this effort; during these webinars, the implementing cities, as well as their peer-reviewers had the opportunity to present their climate adaptation and resilience activities to each other, discuss constraints and opportunities that raised during the pilot process so far, strengthen the co-creative development of the portal and facilitate dialogue between the two tiers of cities that will help the developers finalize the tool. In addition, the peer-reviewers asked questions on the basis of a guideline questionnaire prepared in advance by the local research partner. This was to make sure that the most relevant aspects for the tool development would be questioned and analyzed. After each webinar, the peer-reviewers summarized their feedback and gave recommendations for further development and practical action in a short report as well as provide additional feedback based on the webinars during the review workshop.

Following the tool finalization, additional stakeholder training workshops were organized by each city. Critical infrastructure stakeholders, first responders, IT consultants and emergency management municipal employees were invited to attend these workshops, while identical methodology was used aiming to ensure replicability, comparability, and transferability, to put the emphasis on the project's Circle of Sharing and Learning and to provide detailed training, introducing the portal's main qualities and functionalities. Throughout the pilot implementation process, the pilot cities in close cooperation with their respective research partners, will also organize bilateral meetings with identified stakeholders in the security sectors, but also beyond them, to further explore synergies and collaboration potential between institutions, municipal departments and utilities and the project itself.

The same process that was used for the pilot testing of the Resilience Information Portal will be used for the following project tools; that said, the joint pilot implementation process for the Resilience Maturity Model and Risk Systemicity Questionnaire and the joint implementation process for the Resilience Policies and the System Dynamics Model will follow similar management tactics. Tool testing activities will be guided by the tool developers and project consultants who will be facilitating knowledge and information exchange between partners and city officials and representatives. The Resilience Information Portal provides a platform in which the cities can share best practices implemented in the city during the resilience building process. These best practices can then be included in the Resilience Building Policies as an evidence of how these policies have been or can be implemented in the cities. Therefore, the Resilience Information Portal should help to establish links between European cities, leading to facilitating learning from others (best practices transfer) that will lead to policy suggestions for the Maturity Model, which will then feed into the Resilience Policies Repository.

CONCLUSION AND FUTURE WORK

This project has implemented processes of co-creation to enhance resilience in European cities. In terms of co-creation, the project takes both top-down and bottom-up approaches. The agile development process applied in the co-creation process gathers input from city stakeholders and representatives of municipalities. A conclusion of this bottom-up approach has been that each city exhibits various challenges and problems, resulting in heterogeneous needs and priorities, which demand continuous revision and reassessment of the development process. The advantage of this characteristic has been that it pushes results towards a general and broadly applicable solution, which is the objective of the project's outputs (standardization and uptake by cities outside the consortium). Each of the seven cities contributed various opinions, needs and feedback, presenting a challenge but also the opportunity to ensure that the results are widely applicable.

In terms of communication with citizens, we found cities to be a crucial channel for communication. Municipal websites and press releases issued by cities enjoy a high level of visibility and trust among citizens, representing a highly valuable resource for communication activities.

The collective feedback from cities has showed that so far informing thoroughly stakeholders and city representatives is important and necessary in order to secure active participation and involvement in resilience building activities. Nevertheless, there is need for further focus on stakeholders that are mostly affected by or interested in an issue or challenge. Meaningful and solid stakeholder engagement should be the focus; more particularly on creating and maintaining stakeholder relationships and co-creating the tool having constant input) rather than on innovation. Data input in the portal should be presented in a consistent and solid manner and also filling in gaps or hiccups in city processes and local stakeholder engagement.

City partners identified social media integration as quite crucial in citizen engagement processes; social networking can be rather meaningful in facilitating communication flows and strengthening community involvement but needs to be treated carefully in order to change their effect from outreach to participation and to avoid problems arising from their wrongful use. The project's next steps include the engagement of further cities in testing of the tool and in communicating with project cities. We conclude this paper saying that to ensure high quality pilot implementation processes, there is need for close cooperation and coordination with research and city partners to ensure a clear, well-structured co-creation process. We will continue looking at the effectiveness of the co-creating communication approach of the project and how it enables cities to be more resilient.

ACKNOWLEDGMENTS

This work was supported by the European Union's Horizon 2020 Research and Innovation program [grant agreement number 653569].

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Integrative Risk Identification Approach for Mass-Gathering Security

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ABSTRACT

Effective risk management begins with successful risk identification. Unfortunately, traditional approaches may lead to haphazard and incomplete results. To overcome this, we present a new integrative approach to improve risk identification that sequentially investigates protector-views and narrow scopes using literature review, ethnography, and subject matter expertise. This paper illustrates this approach by identifying man-made and natural threats to mass-gathering events in general, and stadium security as an example. Improving risk identification enhances resilience to known risks by enabling planning and development of targeted response strategies. Working from a more complete portfolio of risk resilience strategies may also improve flexibility and agility to respond to new and emerging risks.

Keywords

risk identification, risk management, resilience, agility, crisis, stadium security, mass-gathering security.

INTRODUCTION

Risk identification is the first step in risk management, and the primary focus of this paper's integrative approach to identifying risk. The motivation is to improve risk management by providing more structured methods to identify risks, so that treatment strategies may be applied to decrease risk. The straightforward ISO/IEC (2009) or NIST (2012) processes to manage risk presumes risks are not being overlooked. Despite good intentions, overlooked risks confuse preparation and defense with luck and probability. A stadium security case will illustrate this integrative approach.

Managers of stadiums, and other mass-gathering events with more than one thousand participants, are challenged to plan and manage security, including development of crisis response plans. This can be perplexing as even similar events held at the same facility may have drastically different risks and outcomes. In addition, security management is compounded with knowledge that terrorist-enabled actors are now targeting these venues, hoping to maximize psychological and economic impact.

Improving mass-gathering security and crises response is important, as millions attend these events. Each year in the United States, for example, over 5.5 million participants attend North American Stock Car (NASCAR) events, and another 165 million attend professional and collegiate sporting events. Identifying risks permits planners to more effectively prepare treatments to either lower risk likelihood, or reduce risk impact. For example, Mass-Gathering Medical Care (MGMC) currently provides standard preventative measures, primary care, and hospital referral, but is challenged to respond, assess, and treat emergency medical services needs (Milsten, Maguire, Bissell, & Seaman, 2002).

All organizations, including mass-gathering events, face uncertainty in the achievement of objectives caused by internal and external influences. The effects from these uncertainties are managed through the application of treatments, that are developed following the influence's identification, analysis, and evaluation (ISO/IEC, 2009). In general, the analyst begins with recognition of risks, and concludes with specific treatment, safeguard, or control recommendations reducing risk likelihood and/or impact. These recommendations are used by senior decision-makers, risk-owners, or protectors to select final implementation choices, given organizational priorities and resource constraints (ISO/IEC, 2009; NIST, 2012).

This paper begins with an overview of the steps in the integrative approach, relating risk management and security concepts, connecting identified risks and treatment strategies, and then applying the integrative risk identification practice and creative methods to identify risks. Mass-gathering events illustrate the method, including the 2013 Boston Marathon bombing and 2015 Stade de France attacks. The paper concludes with steps to guide practitioners to apply the process using protector views, N+1 risks, and reference databases to improve future risk identification.

OVERVIEW: AN INTEGRATIVE APPROACH TO RISK IDENTIFICATION

Table 1 provides steps to conduct an integrative risk identification. Techniques enable asset identification, as well as associated threat and vulnerability analysis. The process begins with a protector-view that values the assets, and may optionally limit scope. Risks are identified and securely recorded, and the process repeats upon completion, expanding the knowledgebase going forward.

Table 1 Integrative risk identification steps

1. Use an existing risk management guideline or standard, such as ISO or NIST (ISO/IEC, 2009; NIST, 2012).

2. Analyze using a specific location for site-specific risks.

3. Use event-type data to identify elements influencing risk, such as communicable disease, weather, demographics, time of year, time of day, alcohol, crowd attributes, known aspects of first responder teams, and political stability.

4. Limit the scope of the investigation using process, function, or some other method (e.g., financial, operational, or regulatory), to make the task more manageable. The analysis can be repeated as needed across other scope domains.

5. Use an asset-oriented method to first list assets, then assign risks to assets:

   - Select a protector-view, including owner, employee, customer, passerby, first responder, etc., to list assets in need of protection, and then rank those assets in importance to the organization.
     - Unrecognized assets may remain exposed if the protector-view is not used, or used too broadly. Some assets are shared, but others are unique to a specific protector and become more visible using the protector-view. A complete analysis repeats this approach for other views.
   - Use the assets to identify a list of risks by noting threats and vulnerabilities for each asset. Use the practice and creative methods of literature review, ethnography, and structured analytics described in this paper.
   - Append the final risk item "N+1" to the list. This is an important signal to the risk owner that risks are never completely identified, and the risk identification process never done. Ideally the completion of one risk identification process would launch the next.

6. Switch to a threat-oriented method, and test asset-sensitivity to new and emerging threats.

7. Switch to a vulnerability-oriented method, and test asset-sensitivity to new and emerging vulnerabilities.

8. Repeat the above steps for other locations, events, domains, and protectors as needed.

9. Use the list of risks to create a high level "dance-card" for each event or business activity. Use this card prior to, during, and after each event, and update the card upon major changes in leadership, technology, facility, or event type. Larger facilities and more complex events might consider implementing an automatic decision aid to reduce cognitive errors.

10. Archive the results in a secure database for monitoring and tracking.

11. Repeat the risk identification before risk treatments are implemented, as new risks may emerge from the treatment.

Assets and associated risks in the form of threat/vulnerability pairs are listed upon completion of the steps in **Table 1**, the focus of this paper.

Subsequent steps for future work assign relative risk values to each risk scenario by using methods to value assets, rank risk likelihood and impact, assign confidence values based on previous experience, and estimate of previously treated risks. The highest relative risks are assigned treatments to reduce likelihood in the best case, or reduce impact otherwise. Lower relative risks are accepted, and added to a watch list to monitor changes in likelihood or impact. Crisis management and communication plans should also be developed for known risks that exceed controls, and new risks. Crisis managers should be trained in mitigation plans to reduce risk impacts, such as evacuation processes, command, control, and communication operations.

RISK MANAGEMENT

The goal of risk management planning is to improve security for an organization's most critical assets. Security describes a goal state of freedom from harm or difficulty for an asset that is valued by a protector, or risk owner. The protector's universe is divided into two states: that which is secure, and that which is unsecure. The goal of the protector is to enhance stability for the asset in the variable "insecure" boundary area separating secure and unsecure states (Manunta, 1997).

Enhancing stability in the border zone of insecurity is accomplished through risk and crisis management. **Figure 1** illustrates that risk management is a proactive planning and preparation process to analyze and control threats around an asset that might take advantage of a weakness or vulnerability in the asset. Risk is described as the likelihood and impact from the alignment of a threat/vulnerability pair acting on an asset. As such, risk management describes the attempt to reduce the likelihood of risk events where possible, or to reduce the impact of events otherwise (ISO/IEC, 2009; NIST, 2012). The bottom of **Figure 1** illustrates that crisis management may be required to provide reactive capabilities for either unforeseen risk events or anticipated events that exceeded preparation.

Figure 1 Risk management should include the planning for crisis management

Figure 2 shows that crisis management extends risk management planning, and should be part of risk management, including assignment of crisis roles and responsibilities, and communication strategies.

The horizontal access represents time, and the vertical access represents operational capacity. At time of the incident, operational capacity is reduced, triggering an incident response. Crisis management uses mitigation plans to provide early detection to react and respond, and incident response plans to return operations to a minimal level, called the "recovery point objective" (**RPO)**, in a specific time, called the "recovery time objective" (**RTO**) (Snedaker & Rima, 2014).

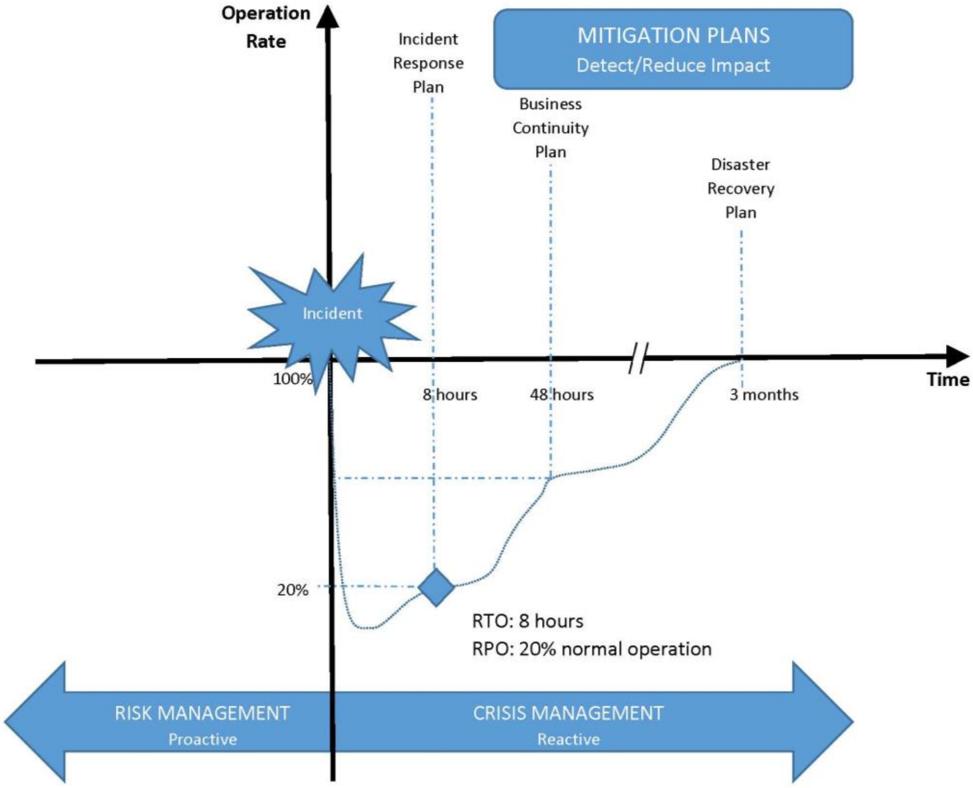

Figure 2 Crisis management describes the reactive processes to mitigate disruptive incidents

Risk Treatments

Although the scope of this paper is to improve risk identification, it is useful to review the connection between identified risks, and the eventual recommendation of treatments for risks. Not all risks can be treated, as organizations are resource constrained, so the greatest *relative risks* from the pool of identified risks are determined based on likelihood, impact, and asset value. Analysts then envision and propose treatments for these risks for decision makers. As such, an incomplete risk pool may subvert the process to identify the greatest relative risks.

Treatment choices lower likelihood through prevention activities, reduce impact through mitigation plans, or lower asset value through substitution. The residual risk that remains after treatment should be equal to or less than the organization's risk appetite. Common risk treatment strategies can be described as avoid, transfer/share, mitigate, accept, and terminate (Boehm & Hansen, 2001; Pew & Mavor, 2007). Strategies may lower one or more risks, or may be combined to further lower a specific risk. Terminating a process does not eliminate all risk, but instead shifts the risk exposure curve from the planned activity to an alternate situation (ISO/IEC, 2009; NIST, 2012).

Treatments that lower likelihood are preferred, such as the avoid strategy. Avoid changes operational processes to replace higher risk exposures with lower ones. Transfer/share strategies may also lower likelihood through contractual arrangements with skilled specialists that possess better systems and expertise (ISO/IEC, 2009; NIST, 2012).

If treatments to reduce likelihood do not exist, such as an outage of grid power, then impact is treated.

Treatments to reduce impact include mitigation plans such as incident response, disaster recovery, and business continuity. Impact may also be lowered by transferring risk to specialists, or reducing financial impact by purchasing an insurance contract. Avoid strategies may also lower impact by changing the operational process (ISO/IEC, 2009; NIST, 2012).

Most identified risks fall below a threshold requiring action, and are thus simply accepted (ISO/IEC, 2009; NIST, 2012), although this should not be used as an excuse to ignore risks. The integrative risk identification approach appreciates the importance of all risks, including accepted risks that have potential to evolve and grow in likelihood or impact. Accepted risks may also be used to seed creative analysis techniques to disclose more substantial risks, or the possibility of risks combining.

Hazards

A hazard is a situation that could threaten a valued asset. **Figure 3** illustrates the range of hazard probability from greater than zero percent to one hundred percent likelihood. Dormant hazards have less than fifty percent likelihood of harming the asset. Armed hazards are imminent, with likelihood greater than fifty percent. Active hazards are currently occurring. Incident describes an active hazard that has completed.

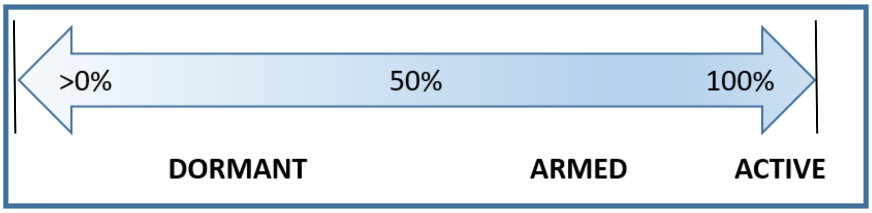

Figure 3 Hazards can escalate and should be identified and tracked

The motivation to apply treatments in risk management is to prevent a hazard from escalating beyond controls to create a crisis situation. **Figure 4** illustrates a resilience approach to risk management using incident response mitigation plans that sense and constrain the hazard's growth to the shaded area under the curve. Extreme events may exceed these resilience plans requiring an agile crisis response.

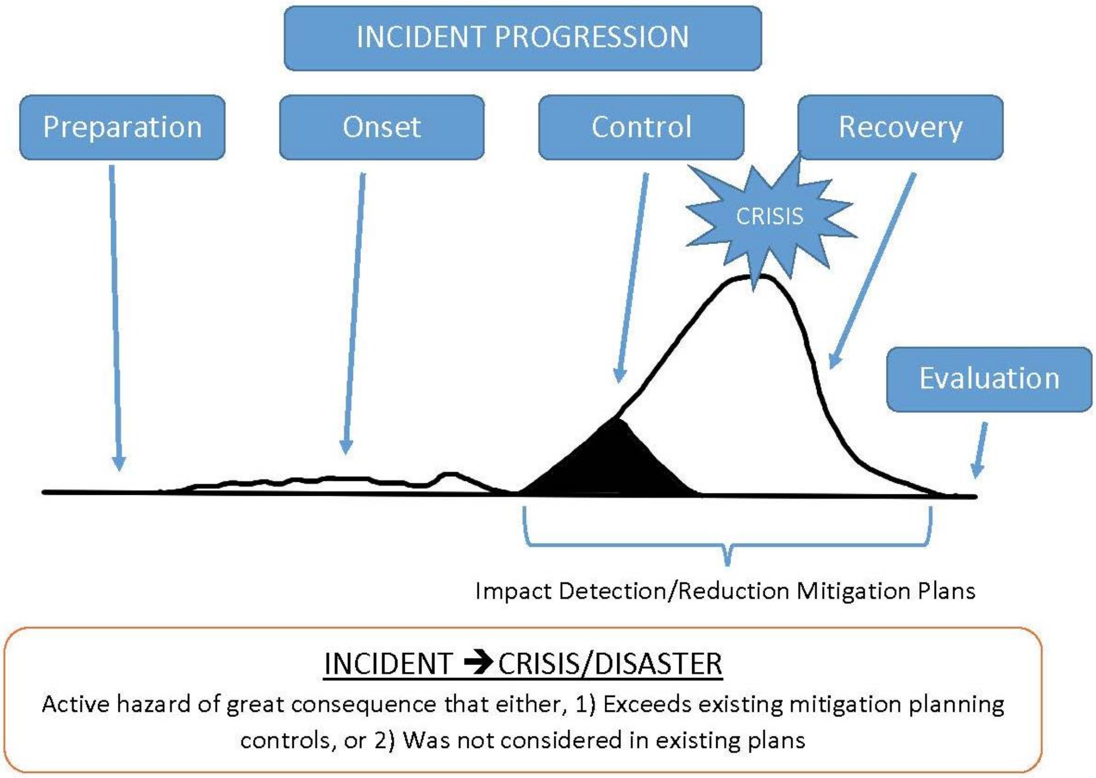

Figure 4 Active hazards may escalate beyond existing controls to create a crisis situation

RISK RESILIENCE AND AGILITY

Resilience is the proactive capacity of a social system (e.g., organization, city, society) to adapt and recover from events exceeding normal and expected disturbances (Comfort, Boin, & Demchak, 2010). Incident response plans designed during risk management provide resilience through early detection and response to known risks.

As discussed, hazards may exceed incident response plans, and require crisis mitigation plans such as disaster recovery and business continuity. These plans should be proactively designed during risk management planning. Disaster recovery plans focus on short-term recovery, including emergency shut-down procedures if necessary, and reestablishment of services. Business continuity plans provide continued operations when the crisis exceeds the disaster recovery plan, including alternate facilities and systems from which to provide operations. These two crisis mitigation plans, disaster recovery and business continuity, may provide resilience to known risks, but their existence may also enhance agility to new risks.

Agility is reactive, building on anticipation of potential changes that might occur in the future, to return to a stable condition (Barthe-Delanoë, Carbonnel, Bénaben, & Pingaud, 2012; Barthe-Delanoë, Ramète, & Bénaben, 2014; Barthe-Delanoë, Truptil, & Bénaben, 2014; Wagner & Disparte, 2016). Adaptive capabilities can leverage risk resilience treatments for known risks to enhance flexibility for agile response to new risks.

INTEGRATED RISK IDENTIFICATION APPROACH

The overall effectiveness of risk management depends on thorough and continuous identification of risks, as opposed to incomplete, non-recurring efforts. Risk analysis performed on an incomplete risk set is particularly dangerous, contributing to a false sense of security. Similarly, non-recurring risk identification prevents disclosure of new risks arising from organizational and environmental changes. Decision-makers deserve to be informed of new risks, and afforded the opportunity to evaluate them in accordance with organizational objectives and resources. Identifying risks, present and future, is necessary to adequately secure an organization's interests (Tchankova, 2002).

The integrated approach to risk identification is recurring, and combines discovery techniques grounded in practice and creativity. Practice-based scenarios recall risks known to have occurred through a review of the literature, including regulatory requirements, ethnography including domain insights gathered by analyst observation, and subject matter expert interviews. Creative-based scenarios identify risks that have not yet occurred, and can be creatively envisioned using Delphi (Markmann, Darkow, & von der Gracht, 2012), brainstorming (C.I.A., 2009), and other structured analytic techniques.

For example, practice-based methods would enable hospitals located in the path of Hurricane Sandy to better prepare from a review of hospitals located in Hurricane Katrina's path. Creative methods would enable airlines to identify new risks arising from risk treatments, such as the mental or physical health risks of a single pilot alone behind a fortified cockpit door.

AUTOMATED METHODS

The identification and management of large numbers of risks from this integrative approach will benefit from automated methods for monitoring and tracking. Automated methods of machine learning and data mining have already enhanced risk identification and assessment of mass-gathering patient presentation rates (Serwylo, Arbon, & Rumantir, 2011), as well as risk areas in financial markets (Ozgulbas & Koyuncugil, 2011), pipelines (Wang, Zhou, & Zhang, 2013), food safety (Xin & Liu, 2015), and cloud security (Ahmed & Abraham, 2015).

Researchers have also applied web services and agents to develop novel architectures for anti-terrorism planning and resource allocation systems (Haynes, Kannampallil, Cohen, Soares, & Ritter, 2008).

Another advantage of automated methods is predictive modeling of risk variables to better manage mass-gathering event security. For example, the patient presentation rate application modeled variables such as number attending, event type, weather (e.g., heat index, humidity, temperature, wind chill), time, and availability of alcohol (Serwylo et al., 2011).

CASE: MASS-GATHERING SECURITY

Mass-gathering security planning is a suitable case to apply the practice and creative-based scenarios using the steps in **Table 1** of the integrative risk identification approach. The practice-methods identify risks published in the literature from known historical events, including published regulatory compliance requirements and other organizational records. This method continues with ethnography, including site investigations and interviews with subject matter experts. The creative-methods, on the other hand, attempt to envision conceivable risk scenarios that have not yet occurred, using Delphi and other structure analytic techniques.

Planning security for mass-gathering events is particularly difficult. Normal circumstances of crowd-related risks, including health, weather, and facility issues, provide a difficult threat-vulnerability surface area to analyze. This is further compounded by terroristic acts targeting these events, from the Black September attacks on the 1972 Munich Olympic games to the more recent German Christmas market attack.

Protector-View and Scope

A complete asset list is required to formulate threats and vulnerabilities to each asset. A protector-view is used to reveal assets from the protector's perspective, and a complete risk analysis may use several protector views selected from associated stakeholders. For example, protector-views for a store might include owner, employee, customer, first responder, public, etc. The scope of the protector's activities can be further constrained to provide more scrutiny in asset identification. Methods to subdivide scope include process (e.g., input, process, output), or function (e.g., hardware, software, database, network, people, and process/facility).

Practice-Methods: Literature Review

Starting with the literature review informs researchers of risks to consider in the divergent/convergent analysis, as well as when conducting the virtual site visit or subject matter expert interviews. Finding risk related literature is recursive, requires a time investment, and may involve various search engines, as well as organizational and regulatory databases. Finding a risk report for a specific location is not likely, so be flexible and search for related literature. Be persistent to find appropriate search terms. This example required a few iterations using Google Scholar to reveal "mass-gathering security" search terms were more effective than "stadium security." One should document search engines and search terms used. Literature includes scholarly reviews as well as industry whitepapers and even news articles.

Stadium and mass-gathering events represent a broad spectrum of known risk scenarios, both natural and man-made, varying in both emergency planning complexity and demand, as well as medical service requirements. The initial review of the literature identified several natural and man-made sources of risk that are summarized in **Table 2**.

Table 2 Mass-gathering hazards from initial literature review

	NATURAL	MAN-MADE	MAN-MADE
TYPE	WEATHER, GEOLOGY, DISEASE	CROWD-RELATED	TERRORISM-RELATED
HAZARDS	• Weather hazards include drought, extreme temperature (hot or cold), and cyclonic Storms • Geologic hazards include avalanche, earthquake, eruption, and tsunami • Disease hazards includes water, air, vector, and food-born	• Hazards include crowd control, event access, fire safety, medical preparedness, and emergency response • Includes errors by attendees and staff, e.g., Hillsborough disaster	• Hazards include intentional man-made crises designed to maximize psychological and emotional stress among victims and witnesses. • Includes denial and deception
SOURCE	Soomaroo & Murray, 2012	Milsten, Maguire, Bissell, & Seaman, 2002	CCICADA, 2013

Natural Risks in Literature: Weather, Geology, Disease

The natural risks in **Table 2** are from a survey of events between 1988 and 2011 reviewing participant death, injury or illness during mass-gatherings. Twenty incidents were triggered by heat (5), cold (4), lightning and storms (5), and disease outbreaks (6) during sports, air shows, rock concerts, outdoor celebrations, and dignitary visits. Weather hazards included drought, extreme temperature (heat or cold), and cyclonic storms; geologic hazards include avalanche, earthquake, eruption, and tsunami; disease hazards include water, air, vector, and food-born (Soomaroo & Murray, 2012).

Man-Made Risks in Literature: Crowd-Related and Terrorism

Man-made hazards in **Table 2** are crowd-related variables, as well as terroristic acts, from a literature review investigating mass gatherings between 1977 and 2002. Crowd variables include crowd control activities, event access, fire safety, medical preparedness, and emergency response. This review identified variables associated with injury-illness patterns, using a medical-usage-rate based on patients-per-ten-thousand-persons in attendance. Crowd variables that increased medical care demand included event type and duration, crowd mood, attendance and crowd density, age, and alcohol and drug use (Milsten, Maguire, Bissell, & Seaman, 2002).

Terroristic acts are intentional man-made crises that use soft targets to maximize economic disruption and psychological stress among victims, witnesses, and the general public. Terrorists use an “attack utility” to measure target effectiveness. Stadiums, and other mass-gathering events, represent a high attack utility for terrorists seeking to maximize disruption and stress, as these venues are difficult to secure, and possess multiple vulnerabilities (CCICADA, 2013).

Practice-Based: Subject Matter Expert Guidelines

Another way to elicit existing risk knowledge is through ethnographic techniques, such as site-observation and subject matter expert (SME) guidelines or interviews. For illustration, research from two university centers will illustrate guides from experts to identify hazards in stadium security.

The first SME guideline is the Command, Control, and Interoperability Center for Advanced Data Analysis (CCICADA) at Rutgers University, in New Jersey, USA. CCICADA has demonstrated expertise by leading several government and non-government organizations to compile a Best Practices in Anti-Terrorism Security (BPATS) guide. The guide’s scope uses fifteen all-hazard National Planning Scenarios[1] to plan responses to a range of terrorist attacks (e.g., nuclear, biological, chemical, explosive, and cyber), as well as natural disasters (e.g., earthquake, hurricane). The guide targets professional and collegiate sporting venues (e.g., baseball, football, basketball, hockey, soccer, car racing) in the United States (CCICADA, 2013).

The BPATS guide demonstrated expertise by using an integrative risk approach consisting of literature review, stadium security expert interviews, facility visits, and workshops. The literature review included incident After-Action-Reports, academic research reports, published articles, and special event operational procedures, among others. They also took advantage of best practices and research from other domains. The BPATS guide is one hundred fifty-five pages, and its Best Practices Matrix is another seventy-three pages. Approximately six-hundred feasible best practice risk treatments are identified in functional areas of risk assessment, staffing (e.g., leadership, organization, and authority), information management, operations, and communications. Risks meriting best practice treatment, or “protective measures,” are rated from strongly recommend, recommend, to suggested. Metrics are also provided to evaluate performance for each best practice (CCICADA, 2013).

The second SME guideline is the National Center for Spectator Sports Safety and Security (NCS4) at the University of Southern Mississippi. The NCS4 developed best practices for collegiate and professional sporting event risks at annual workshops hosting event managers, law enforcement, medical, and other public safety representatives. Similar to the BPATS guide, NCS4 advocates continuous, or cyclical, improvement, and treats these guides as living documents. Their “2015 Intercollegiate Guide” is one hundred and seventy-two pages long and includes approximately seven hundred best practice recommendations. The NCS4 guide arranges best practices around nine functional areas: game day plan, crowd dynamics/management, emergency action planning, routine non-game day operations/measures, risk and threat assessment/vulnerabilities and planning, sport facility design/environment, staffing (e.g., performance, development, training, and certification), security and safety awareness culture, and technology use (e.g., implementation/innovation/information management) (NCS4, 2015).

As the NCS4 and BPAT guides use different methodologies, their results are not identical, although there is overlap in the list or risks and associated best practices. Both guides advocate use of the National Incident Management System’s (NIMS) Incident Command System (ICS) during incident response. The ICS specifies a “Unified Command” doctrine to align and organize the response of incident commanders from law enforcement, fire, medical services, and venue security. The Unified Command promotes efficient interagency communications by operating from a common command center facility, staffed with representatives from each agency. One difference is that the BPAT guide includes metrics to evaluate compliance, although the NCS4 most likely provides this level of detail in their private consulting certification processes.

[1] List of National Planning Scenarios developed by the Federal interagency community https://emilms.fema.gov/IS800B/lesson5/NRF0105060t.htm

Creative-Methods: Structured Analytics

Next, new and emerging risks, and site-specific risks, can be creatively identified using structured analytics, such as divergent/convergent thinking, or the Delphi method. This builds upon the more than seven hundred known risks from the literature review and SME guideline information. For example, neither of the referenced SME best practice guides specifically address treatment of drone threats. Further, these creative methods can also test unproven risk treatments, such as those accompanying evacuations from mass-gatherings.

Delphi is one technique to conduct creative evaluations in general, with potential value for risk assessment. Rand Corporation developed Delphi to structure group communication of complex problems. The technique typically involves several rounds of communication, often conducted remotely, and with some degree of anonymity. The technique may begin with an initial phase contributing problem information, followed by a second phase discussing divergent group member views, followed by a final evaluating phase. Delphi has been recognized in risk analysis as both a method to identify risks, as well as to subjectively assess uncertainties (Linstone & Turoff, 2002). Researchers applied Delphi research to man-made risks in global supply chains with uncertainty of type, location, and affected supply chain partners. They found the Delphi technique improved several areas, including risk identification and measurement (Markmann et al., 2012).

Structured brainstorming, or divergent/convergent thinking, is another creative technique permitting groups to identify and assess risks. This technique is conducted in two phases. The divergent phase lists as many ideas as possible, free of constraint or criticism. Techniques reduce "power of the pen" constraints, and groupthink. Successful divergent results are based on quantity. The convergent phase organizes the divergent results into related categories, and ranks them. Success in the convergent phase is an ordered list of risks (C.I.A., 2009). The two-phases of structured brainstorming effectively identifies new risks, as well as assigns relative importance to each (Yoe, 2011).

MASS-GATHERING TERRORISM RISK

The recent terrorist attacks at the 2013 Boston Marathon bombing and the 2015 Stade de France attack contribute to our knowledge-base of mass-gathering security, but also provide opportunities to improve resilience planning using integrative risk identification. The protector-view is the crisis manager, and the scope is limited to mitigation plans following a terrorist attack, including use of social media and cell communications, and decisions to evacuate or shelter in place, and assign travel restrictions.

The Boston Marathon explosion was an isolated attack by two brothers that killed three civilians, and injured an estimated 264 others. The 2015 Stade de France attack was part of a more sophisticated series of attacks involving seven perpetrators in Paris and the city's northern suburb, Saint-Denis, killing 130 people, and injuring 368 others. Both events invoked public restrictions on movement and charted new territory in social media and public involvement in immediate crisis response and subsequent police investigation. While social media enhanced public awareness and response to the isolated Boston attack (Montgomery, Horwitz, & Fisher, 2013), poor cell service reduced panic in coordinated attacks at the Paris Stade de France (Borden, 2015). In Boston weapons included IEDs, a handgun, and a car. In Paris the attackers were more sophisticated using assault rifles, hand grenades, and suicide belts, in attacks outside the Stade de France, in cafés and restaurants, and inside the Bataclan theatre (de la Hamaide, 2015).

Following the Boston explosion, the Governor requested citizens to voluntarily "shelter in place" during the four-day manhunt controversially (and probably extra-constitutionally) halting commerce and travel in Boston, Watertown, and Cambridge. Eventually one perpetrator was killed, and his brother apprehended (Montgomery et al., 2013). Police initially attempted to use social media to enlist public support in the identification and location of the two persons of interest. Instead, officials needed to squelch ad hoc social media vigilante efforts, expressing concern that Twitter and Reddit users contributed to the exchange of bad information, heightened panic, and made public information that could compromise officers' position and safety (Chang, 2013).

The attack on the soccer game at the Stade de France could have been worse, had security not effectively blocked attacker access to the stadium, protecting French president Francois Hollande and 80,000 other fans. Further, poor stadium cell coverage permitted the game to continue without participant awareness of the attacks, avoiding panic. The need for more planning was evident at the end of the game when fans were initially herded to one of two exits, before being returned to the field to await further instruction (Borden, 2015). Similar to the Boston bombings, although more restrictive, France issued the first of five extensions of emergency powers to enhance police authority (BBC, 2016).

It is conceivable that the Paris Stade de France evacuation began as part of a structured resilience plan that was adapted in an agile response to new information of coordinated attacks, and determined safer to have fans wait in the stadium before receiving the all clear to exit. Although likely unplanned, it was fortuitous that poor cell service reduced panic among unaware fans.

These events represent an evolving threat landscape for mass-gathering events, increasing in weapon sophistication and coordinated attacks. These represent an increased need for creative tabletop training exercises to prepare for both the known and possible.

CONCLUSION

At this point benefits are evident in ongoing risk identification, and the need to grow a knowledge base from previous experiences. The integrative approach to increase identification of risks is a method to create lists of assets and associated threat/vulnerability pairs. Practice and creative-methods combine literature review, ethnography, and structured analytics to identify risks. In addition, the creative-methods can help investigate risks arising from proposed treatments.

Integrative risk identification derives value from creating resilience plans to identified risks, and as such creates long lists of risks that need managed. Additionally, resilience plans may combine to enhance flexibility for agile response in crises.

ACKNOWLEDGMENTS

We would like to thank the reviewers for the positive and helpful comments.

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Emergency Plans are Software, too

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ABSTRACT

In one of the most influential papers in the history of Software Engineering, L.Osterweil analyzed the nature of both software and software development processes to conclude that the latter shared many characteristics with the former and, as a consequence, software development principles and techniques could be applied in the definition and exploitation of processes. Here, we do an imitation exercise to claim that emergency plans are advanced software artifacts and, hence, modern software development principles, methods, techniques and tools can be used in their development and enactment. We advocate for a change of paradigm in which the idea of emergency plans as text-based documents is replaced by that of active, complex digital objects with state and behavior that drive emergency response processes, and also several preparedness activities such as drills and training exercises. These new plans are the result of a systematic process we call Emergency Plan Engineering.

Keywords

Emergency Plan Engineering, Emergency Plan Management, Software Engineering.

MOTIVATION

Human activities are generally described in terms of (repeatable) ordered sequences of tasks; setting up a new device, cooking a particular meal, or replacing a damaged car piece are examples of the so-called *processes*, in the broadest sense of the term. Sometimes processes are physical, that is, they are intended to manipulate or create tangible objects, and performed by humans, whereas in other cases processes are intended to drive the performance of different actors (both humans and computers or robots) with some purpose, without producing any physical outcome. Be it physical or not, a process is normally described by means of a process specification. While a process is the actual execution of its component tasks, a process specification is the description of how the process must be carried on (Osterweil, 1987). A process specification is, additionally, the *reification* of a process model that can be then enacted as many times as desired in the form of process instances.

There is no single way of expressing process specifications: pictorial representations drive users in the assembly of furniture, cooking recipes are typically specified in natural language, and business processes are specified in formal, executable languages in modern workflow management systems (Sheth et al., 1996). Sometimes, the deployment of a process specification requires some type of equipment or *hardware* that must be brought into scene for its manipulation during the process enactment.

Emergency management is the generic name that denotes sets of knowledge intensive processes that have as a final goal the protection of people and infrastructures in front of natural or man-made disasters. Following a top down description, numerous authors have defined emergency management lifecycle models, which structure the management activities in sets of stages that are applied either sequentially or iteratively. These stages typically include mitigation, preparation, response and recovery, being the response the most critical one since it starts at the very beginning of the disaster and must be performed in difficult conditions. To avoid failures, the preparation stage deals with the training of the response teams and potential victims using the emergency plan as the master book of knowledge.

Emergency responses are processes where a heterogeneous set of participants collaborate in the solution of crises with the aim of preserving life and properties of the affected citizens. They are processes of high complexity, where many dimensions (e.g. communication, coordination, information management, collaboration) have to be considered (Canós et al., 2004), and with strong *hardware* requirements related to the safety equipment necessary to respond adequately to emergencies. An organization's or community emergency plan drives the response to any possible threat in terms of information and processes that are enacted during the responses. These processes coordinate the actions of the different actors involved in the response, providing the information required to solve a task, if needed. This duality Information/Process resembles the classic separation between data structures and algorithms of structured programming approaches since the 1970s (Wirth, 1976), apparently diminished with the advent of object-oriented programming, but that persists in modern software development techniques. However, emergency plan development has not evolved at the pace software development did.

Current emergency plans are plain text documents, with some pictures and maps attached, that use natural language to describe the response processes. Given the well-known limitations of natural languages for the specification of actions (ambiguity, ellipses, etc.), any plan enactment needs the manual coordination of a response manager, typically working at the control room. Monitoring and logging the actions performed during the plan enactment must be made by means of ad-hoc utilities, often available as part of the communications system. Moreover, access to plan information requires having physical copies of it (or its rendering in some electronic device), without any chance to selective (or customized) content delivery. Such limitations may result in situations where the access to the emergency plan becomes a bottleneck in the global response performance (Canós et al., 2004).

Such a situation can improve notoriously if the management of emergency plans takes profit of the knowledge acquired in other disciplines for decades. Specifically, we claim that dealing with emergency plan development from a Software Engineering perspective brings emergency management to a new level of practice. Attending to the similarities between emergency plans and software products, we advocate for adopting methods, techniques and tools developed by software engineering researchers and practitioners in the past and adapting them to lead to what we call *Emergency Plan Engineering*.

Paying attention to the way software is produced (in the ample sense of the term) can help to produce emergency plans that take profit of modern modelling techniques and execution platforms not present in current frameworks. To support our argument, we will point out the similarities between software and emergency plans; later, we will give a first approach to the definition of Emergency Plan Engineering. We propose the definition of an emergency plan development lifecycle as the meta-process specification that guides the elaboration of emergency plans. We analyze the challenges of each stage of the lifecycle, and look to the history of software engineering to find ways to achieve the goals of planning teams. We also align the emergency plan development lifecycle with the emergency management lifecycle, and enumerate the challenges that putting Emergency Plan Engineering in place raises at the technical and methodological levels.

This paper is structured as follows. We first try to show how natural is viewing emergency plans as software, since they share many characteristics. Then, we give clues about the advantages and challenges that the application of modern software development techniques to the development of advanced emergency plans.

EMERGENCY PLANS ARE SOFTWARE, TOO

There are many similarities between software and emergency plans that led us to choose such a categorical sentence as title of our paper. In this section, we list some of the most remarkable. As a matter of fact, the development of software and of emergency plans are much closer than one may suspect, too. However, there remain differences that also deserve to be signaled, since there will show lines of research for the development of Emergency Plan Engineering.

As agreed by the Software Engineering community, the definition of software includes three components (Pressman and Maxim, 2015):

- a set of statements written in some language that, when executed, provide the desired function and behavior;
- the data structures that help managing information properly, and
- the documents describing their operation and usage.

And there is consensus within the Emergency Management community in that an emergency plan: *"... is a written set of instructions that outlines what workers and others at the workplace should do in an emergency. An emergency plan must provide for the following:*

- *emergency procedures, (...)*

- *testing of the emergency procedures—including the frequency of testing, and*
- *information, training and instruction to relevant workers in relation to implementing the emergency procedures."* (Quoted from (Safe Work Australia))

We can find at least two similarities in both definitions. The response plan process specification (i.e., the emergency procedures) can be seen as the set of instructions to be followed to solve the emergency, including the data structures as the information contained in the plan. The documents in case of software could, to some extent, be part of the instruction mentioned in the definition of emergency plan. As for differences, notice that specifying the participants in charge of the tasks composing the response procedures requires models richer than those of programming languages (see later in this paper).

Like software products, emergency plans are mostly logical elements: they are developed rather than manufactured, they do not suffer deterioration for their use, and unlike physical equipment, which can be (re)used in different settings, emergency plans are produced via custom development, instead of assembling existing components. And, like source code listings of software products, the printed version of an emergency plan is a representation in a specific language. However, current emergency plans are not written in executable languages, which means that they cannot be interpreted by a sort of "plan compiler" to automate the response to emergencies.

The crisis of software (Pressman and Maxim, 2015) was a critical situation for the software business occurred at the early 1970s. Different studies pointed out that numerous software projects, very complex and expensive, resulted in big failures or required many changes before their use. The main problems came from three important facts: the software products were of low quality, their development costs were very high, and they were delivered with unacceptable delays. Numerous causes found for the crisis situation could also apply to emergency plan development: the non-physical nature of plans makes it difficult to detect errors, the use of informal languages, craft approaches to plan development, problems derived from teamwork, problems in the communication with *users* (the organizations as final recipients of the plans), and the lack of a clear management of plan development projects.

The solution to the software crisis came with the rise of Software Engineering as a new discipline in computer science that proposed the use of engineering principles to transform a craft activity like programming into a rigorous approach to software development. Research and development in this new field started with the search for new methods, tools and procedures for the development of high quality software [Pressman]. Giving a historical record of the advances in the discipline is out of the scope of this paper, but it can found elsewhere (Brennecke and Keil-Slawik 2006; Mahoney, 2004). Our current research work consists of borrowing some of the principles of Software Engineering for the consolidation of Emergency Plan Engineering as a new discipline within Emergency Management. An outline of our approach follows.

A ROADMAP FOR EMERGENCY PLAN ENGINEERING

Emergency Plan Engineering is intended to be a systematic approach that uses modern software development techniques and tools in the development of more expressive, flexible and manageable emergency plans. It is a horizontal approach that involves many disciplines. In this section we outline possibilities for innovation respect to state of the art emergency plan elaboration practices. As mentioned earlier in this paper, many innovations in the Software engineering field can be used to fulfill the main goals of the discipline. We first define describe the meta-process that defines the sequence of activities involved in the development of emergency plans (that we call "The EPE Process", and then focus on each of these activities to see which Software Engineering techniques can support them.

The EPE Process

Figure 1 shows a representation of the EPE process. It is composed of two subprocesses (Derniame et al., 1998). On one hand, the Production Process includes all the technical activities related to the development of emergency plans; we will refer to it as the *EPE lifecycle*. On the other hand, the Management Process controls the Production Process to ensure that plans are developed in time, within budgetary constraints and with the adequate levels of quality. It also provides the support to the administrative tasks required by legal regulations of emergency plan management. Both processes are executed after a need from the environment is manifested (i.e., the obligation of elaborating an emergency plan), and use development and project management technologies, respectively, to perform their different component tasks.

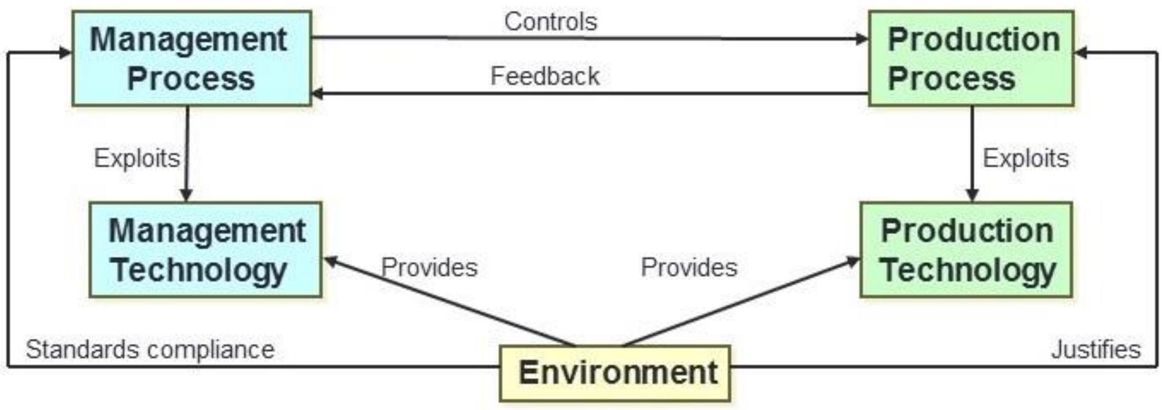

Figure 1. The EPE Process. Adapted from (Derniame et al, 1998).

The EPE lifecycle is an iterative and incremental engineering process that allows the plan to evolve as each iteration progresses, just like the software lifecycle models do. Depending on the nature and complexity of the problem, different lifecycle models can be used. Figure 2 shows a generic model which can be tailored to specific cases if needed. It consists of a set of stages, which are in turn subprocesses composed of several tasks that produce artifacts to be used in later stages of the cycle. A detailed view of the stages is out of the scope of this paper, but notice that they can be described using a process modelling notation like BPMN.

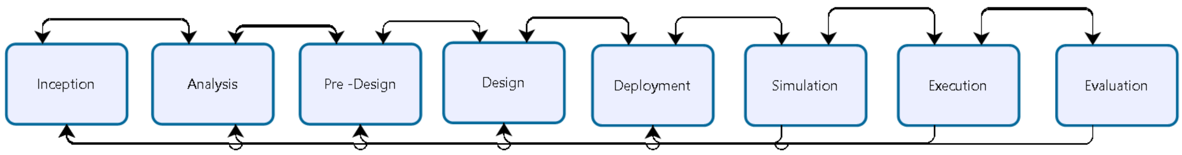

Figure 2. One EPE Production Process or Lifecycle

In the Inception phase the basis of the emergency plan to be developed is established. It is necessary to develop a context analysis to clearly determine the system to be protected, as well as its geographical properties. Once the system has been defined, the planning team should be set up. Project management techniques can be used to create a project plan that will define the EPE Management Process.

The Analysis phase starts with the identification of the users of the emergency plan, that is, those in charge of the execution of the plan and the provision of feedback to eventual improvements. Then, the risks and the possible scenarios where the risks are presented must be analyzed. It is important here to define very clearly the resources that take part in such scenarios and to verify that all risks are handled. Some techniques borrowed from Requirements Engineering –a subdiscipline of Software Engineering aiming at capturing requirements of software products- such as interviews, workshops and use cases, can be used by the work team to better understand the specific requirements and have a more accurate system description. The ability to use existing scenarios that can be coupled to the new emergency plans and be able to design reusable risks scenarios for future work is an intrinsic policy within EPE. Risk analysis methodologies such as those introduced in (Scarfone and Orebaugh, 2004; Caralli et al, 2007) can fit within the EPE approach.

The pre-design and design phases are the actual assembly stages where the alerts, alarms and the coordination plan are determined. These stages configure the implementation of the plan. Rapid prototyping and simulation techniques that allow the off-line evaluation of the results of the emergency plan with respect to the scenarios elaborated in the Analysis phase will be of great help. Business process modelling techniques will be at the core of plan development tools with regard to the response plan analysis and modelling.

In the Deployment phase, a robust and enhanced model of the emergency plan distributed to all stakeholders. Depending of the results of the Inception stage, the plan deployment can take different strategies. For small organizations, standalone configurations, including a plan execution server can be enough, whereas for large organizations the use of Cloud environments under SaaS (Software as a Service) or even PaaS (Platform as a

Service) would be better suited.

The utility of emergency plans goes beyond the Response phase of the Emergency Management Lifecycle. An executable plan can be the central piece of modern training environments based on simulation in which security experts can define emergency scenarios as traces in the process model representing the plan. The plan execution system (based on a process support system) is able to log all the activities performed, so post-mortem analysis of the exercise can provide very valuable feedback to response officers. This would be the principal action developed in the Simulation stage.

The execution of the plan takes place in case of actual disasters. Again, the plan execution engine is in charge of the coordination of all the participants in the response according to the plan model. As in the Simulation stage, every action will be recorded for further analysis. All the records will be analyzed after the execution has concluded to find defects and improve the plan in further iterations of the lifecycle.

The proposed lifecycle requires sophisticated software environments: facilities for requirements analysis, process design user interface design, information retrieval, need to be assembled into a service-oriented architecture. Merging process models with knowledge models supporting the rich informational requirements of emergency responses must be done via repositories that exploit technology developed within the Digital Libraries community. Existing plan management environments such as SAGA (Canós et al., 2013) should be enriched with meta-process facilities to provide the methodological support that EPE provides. And last, but not least, relevant results in the development of emergency management systems –such as the role-based approaches defined in the DERMIS system (Turoff et al., 2004)- will be applied at the right stages of the EPE lifecycle.

A cross-disciplinary approach

Emergency Plan Engineering raises many challenges that, instead of just reusing knowledge, can generate new results in many disciplines. Table 1 represents the presence of an incomplete list of domains in the different stages of the EPE lifecycle. Having emergency plans distinctive characteristics from "regular" software artifacts, we believe that those differences will require research and development of new methods and tools in some of these fields to cope with the complexity of emergency plan development. User-centered design, product line engineering, software architecture, and many other fields can be also relevant in particular cases.

	INCEPTION	ANALISYS	PRE-DESING	DESIGN	DEPLOYMENT	SIMULATION	EVALUATION
Project Management	X	X	X	X	X	X	X
Requirements engineering	X	X					
prototype			X	X			
Use Case	X	X					
Risk management			X	X			
Quality Management					X	X	X
User Interfaces					X		
Process Modeling				X			
Cloud					X	X	X
Agile Methodologies	X	X	X	X			X

Table 1. Some disciplines and practices used in EPE

Finally, we want to focus on customization. Current emergency plans are flat documents, often large, that produce information overload in some of their potential users. Having plans specified as processes, with the participants identified, opens the door to a change of paradigm where the model "1 plan-n users" is replaced by a more flexible "1 plan-1 user". Current software and hardware technologies are powerful enough to support the customized generation of plans in which each participant in a response (included the potential victims) receive the right information (and no more) at each time.

Our intention, in this ongoing work, is to wrap up a large part of SAGA (all the modules related to plan management, including editing and executing) with a methodological layer, and show how much software engineering research advances can help us. Actually, our intention is to transform the way plans are developed so far into a more systematic process, and to provide process support tools (mostly available as SAGA components). From our experience in the design of the QuEP framework, that evaluates how plans are managed by organizations, we believe that a process like EPE could be the first step towards the definition of a framework to evaluate the quality of emergency plans, probably using also quality metrics derived, at least partially, from the software quality discipline.

ACKNOWLEDGMENTS

The work of J. H. Canós is funded by the Spanish MINECO under grant CALPE (TIN2015-68608-R). The work of D. Piedrahita is funded by Indea Ingenieria de Aplicaciones S.L.

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A Heuristic Approach to Flood Evacuation Planning

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ABSTRACT

Flood evacuation planning models are an important tool used in preparation for flooding events. Authorities use the plans generated by flood evacuation models to evacuate the population as quickly as possible. Contemporary models consider the whole solution space and use a stochastic search to explore and produce solutions. The one issue with stochastic approaches is that they cannot guarantee the optimality of the solution and it is important that the plans be of a high quality. We present a heuristically driven flood evacuation planning model; the proposed heuristic is deterministic, which allows the model to avoid this problem. The determinism of the model means that the optimality of solutions found can be readily verified.

Keywords

Flood Evacuation Planning, Heuristic, Deterministic, Multi-objective optimization

INTRODUCTION

Flooding is the most frequent and high-risk natural disaster to affect the UK (Defra 2012). There have been several severe flood events in the UK's recent history (Kelman 2001; Pitt 2008; Risk Management Solutions 2013). As the climate changes, more extreme weather is expected to occur – and more floods. Flooding has the potential to cause fatalities, the displacement of people and damage to the environment. The disruption caused by flooding compromises the economic development and economic activities of the community (Defra 2012). Although environmental agencies aim to reduce the likelihood of flooding by managing land, rivers, coastal systems and flood defences. However, it is a natural process that cannot be eliminated (Defra 2014).

Because floods cannot be prevented environmental agencies create flood evacuation plans, these are used by local authorities and emergency services to manage the evacuation of people in a flooded area or an area expected to flood (Environment Agency 2012; Defra 2014). The plans contain optimal or near-optimal routes to evacuate people from high-risk locations to safe locations. However, as flood waters rise some routes are no longer accessible, meaning alternative routes must be used to evacuate people. The plans are created using static maps, historical flood data for the area, and scenario-based studies predicting the extent of inundation (Defra 2014).

Flood evacuation models help environmental agencies create plans by providing them with routes to evacuate people. To meet this end, the flood evacuation models require knowledge of the road network and a set of safe locations. The safe locations, usually located on high ground, are safe from the rising flood waters and provide shelter, food, and medical assistance (Lumbroso et al. 2010). It is typical to use pre-existing buildings such as community hospitals, churches and schools as safe locations. However, areas with high population densities may, also, require temporary shelters (Cabinet Office 2014).

Flood evacuation planning models solve the problem of distributing evacuees to safe locations while minimising the evacuation time (or: distance travelled) and prevent over-allocating people to any given safe location. Minimising evacuation time is analogous to the shortest path problem and for which there exist well-established algorithms.

However, this is true for where there are no capacity constraints at safe locations, so the problem has two conflicting objectives 1) send evacuees to the closest safe location and 2) not to send too many to any single location. Contemporary models represent the problem as a Multi-Objective Problem (MOP) and solve them using evolutionary algorithms (Saadatseresht et al. 2009; Yang et al. 2015). This approach means such models inherit several disadvantages. Even with the use of evolutionary algorithms such as NSGA-II (Deb et al. 2002) that help to mitigate a fast convergence on a local optimal, the stochastic nature of evolutionary algorithm means the optimality of the solution cannot be guaranteed.

This paper proposes a new heuristically driven flood evacuation planning model. The model is a potential alternative to evolutionary (or: genetic) stochastically driven models and as a result, does not inherit the same disadvantages. The model is expected to yield high-quality solutions without performing an exhaustive exploration of the search space; this gives the model good runtime performance and scalability.

Current research (Yang et al. 2015) on flood evacuation planning identifies the flooding as a dynamic problem that needs responsive solutions. The proposed model as well as being deterministic also runs in polynomial time; the runtime characteristic means that this model may be used to find solutions in dynamic search spaces. In other words, as the search space changes, a new high-quality solution can be found by the proposed model quickly enough to satisfy the dynamic problem.

The paper is structured as follows. In the next section, there is a brief overview of the current approaches used to solve the problem of flood evacuation planning exploring the strengths and weaknesses of the different approaches and how the proposed model in this paper is expected to differ. The next section presents the proposed model alongside a numeric case study that serves to both explain and demonstrate the model. Finally, a discussion the future research interests and expectations.

FLOOD EVACUATION PLANNING RESEARCH

Evacuation planning is studied from several different perspectives ranging from models to predict evacuee behaviour, the development of methods to identify potential shelter sites, and route planning algorithms for evacuations. (Hamacher and Tjandra 2001) classified evacuation plans into two scopes, microscopic and macroscopic. Microscopic planning refers to perspectives that consider small-scale operations such as evacuee behaviour whereas macroscopic planning refers to perspectives that consider operations performed on a population. In this paper, we are concerned with models that work on the macroscopic level of evacuating an entire population.

Yamada (Yamada 1996), created two models to optimise a cities emergency evacuation plan, both models represent a city as a graph with vertices representing Places of Refuge (PR) and Residential Areas (RA). The first model considers the trivial case where there are no capacity constraints at PRs; this problem is analogous to the shortest path problem and is solved using well-established algorithms. This model is of interest, even though the problem it solves is simple, the model is used to gauge the quality of the solutions produced by his second model that considers capacity constraints at PRs. The second model treated the problem as a minimal-cost network flow problem, by creating a second graph with an addition source and sink node connected to all RAs and PRs respectively and applied known methods (Ford Jr et al. 1963). This approach has several advantages; it is a high-performance model and therefore is scalable to large problems and by the measure of the first model produces high-quality solutions. However, unlike contemporary methods (Kongsomsaksakul et al. 2005; Saadatseresht et al. 2009; Yang et al. 2015) it does not consider the evacuee allocations simultaneously, leading to potentially unfair evacuation plans.

Lu et al. (Lu et al. 2005) present a heuristic algorithm that produces sub-optimal solutions for flood evacuation planning with capacity constraints at safe locations. Their heuristic approach discovers high-quality solutions at considerably reduced computation cost, and when applied to large-scale problems found in urban areas is still performs quickly. Lu et al.'s model addresses the limitations found with linear programming approaches that can find optimal solutions, by producing time expanded graphs whereas their solution works on a single graph representation of the flooded area. Lu et al.'s model demonstrates that heuristics can generate high-quality sub-optimal answers for and their performance characteristics are desirable for large scale problems. However, their heuristic does not consider evacuee allocations simultaneously.

Kongsomsaksakul et al. (Kongsomsaksakul et al. 2005) presented flood evacuation planning as a Stackelberg game with the local authority as the (leader) determining shelter locations and evacuees as the (follower) choosing a shelter and route. Formulating the problem as a bi-level programming problem with the upper level modelling the shelter locations and a Combined Distribution and Assignment (CDA) model for the evacuees' decision as the lower problem. The bi-level programming problem is solved using a Genetic Algorithm (GA). Kongsomsaksakul et al.'s model performs a simultaneous stochastic search for solutions; this approach addresses that flood evacuation planning has multiple objectives, as modelled in the Stackelberg game, with both objectives considered at the same time. However, the GA used in this model limits the model to small-to-medium sized problems as the GA dominates the total runtime. The stochastic search also does not provide any guarantee of the discovered solution's optimality.

To create effective evacuation plans, it is important that models have access to geospatial data. A Geographic Information System (GIS) can provide this data as well as methods for route planning, and flood modelling (Mansourian et al. 2006; Chen et al. 2009; Saadatseresht et al. 2009) utilise GIS in their work on emergency management and evacuation planning. Although using GIS-assisted models is a relatively recent development, there were geospatial components in older models too.

Saadatseresht et al. (Saadatseresht et al. 2009) use a GIS in conjunction with a multi-objective evolutionary algorithm to create a GIS-assisted evacuation planning model. Saadatseresht et al.'s model simultaneously considers two objective functions, 1) population assigned to the each safe area is less than or equal to its capacity. 2) Buildings with the largest populations have priority over those with smaller populations. The first objective is common sense as we cannot assign more evacuees to safe areas than there is available space. The second objective reduces the cumulative time of evacuation for the population. In other words, the greatest number of people reach safe areas in the shortest time. It can be seen that the two objectives conflict with one another. Saadatseresht et al. treat the problem as a multi-objective optimisation problem while considering two objectives simultaneously. An evolutionary approach is used namely, NSGA-II (Deb et al. 2002) which helps to prevent an early convergence on a local optimal and provides mild performance improvements over other evolutionary approaches (Deb et al. 2002; Saadatseresht et al. 2009). The model considers all allocations simultaneously and uses an evolutionary approach that mitigates some of the associated disadvantages. However, the stochastic search does not guarantee the optimality of the discovered solution.

In 2015, Yang et al. proposed the first dynamic flood evacuation planning model. Their model is dynamic because it considers the extent of inundation. In other words, during a flood event, their model is aware that some routes will become inaccessible due to the rising flood waters and provide an updated evacuation plan. Yang et al.'s model must update the evacuation plan at regular intervals to maintain its dynamic property. The problem is encoded as a binary optimisation problem, and the model uses a Genetic Algorithm (GA) to solve it, this encoding gives the model high performance as the GA only needs to modify a decision variable. Yang et al.'s model has a time-critical constraint and presents the need for efficient models that produce high-quality solutions. Similar to (Saadatseresht et al. 2009) the fitness function used to evaluate the population simultaneously considers all allocations and the binary optimisation encoding allows this model to perform much quicker. However, the stochastic search does not guarantee the optimality of the discovered solution.

The model proposed in this paper uses a heuristic to find high-quality non-optimal solutions for the problem of distributing evacuees to safe locations during a flooding event. The model considers all allocations simultaneously and prioritises them based on a heuristic. The heuristic considers the relative distances of evacuation locations and safe locations, as well as the capacity constraints at safe locations. The model can be briefly described in the following steps. First, initialise all possible evacuation to safe locations allocations. Order the allocations based on the heuristic function, select the current 'best' allocation and add it to the flood evacuation plan. Apply the heuristic to the remaining allocations and repeat the selection process until all evacuation locations have been assigned. It can be seen that after each selection the model considers all remaining allocations simultaneously.

The proposed model assesses the multi-objective problem in a similar fashion to that of the evolutionary/genetic approaches already discussed in this section except there is not a stochastic exploration of the search space, which is the reason they cannot guarantee the optimality of the discovered solutions. The model proposed avoids the search and therefore does not inherit the same disadvantage. It should also be easier to verify the quality of solutions as the approach is deterministic. Similar to (Lu et al. 2005) the approach should have a relatively high performance and scale to large problem sets, due to the heuristic approach. The proposed model uses normalised relative distances, this allows the model to distribute evacuees fairly, but that loss of information can result in non-optimal solutions.

HEURISTIC FLOOD EVACUATION PLANNING MODEL

The present section describes the new heuristic model alongside a numeric case study which is used to describe and demonstrate the model. The model solves the problem of allocating evacuees located at evacuation locations to different safe locations while minimising evacuation time (or: distance traveled) while considering the capacity constraints at safe locations.

The first part of the model requires that a set of evacuation and safe locations be known, in this paper it is assumed that local authorities have taken such measures in preparation for a flood event. The chosen safe locations should be secure from the effects of inundation and have enough space to accommodate evacuees.

Numeric Case Study

Figure 1. Numeric Case Study

Figure 1 is the numeric case study examined in this paper; the figure shows a graph with safe locations as filled vertices labelled with σ's and evacuation locations as unfilled doubled bordered vertices labelled with ε's. The line (or: edge) between any two vertices represents a route between them, and the distance is labelled at the midpoint. The distance between vertices that are not adjacent to one another is calculated as the sum of all edges visited on the path between the respective vertices. The population at each evacuation location and the capacity at each safe location is shown in brackets at each node label. In the numeric case study, there is a total of 15 000 evacuees and 15 000 available spaces at the safe locations.

Shortest Path Trees

The first step in the model is to calculate the shortest paths for all evacuation locations to each safe location. In this model shortest path trees are used to answer these queries. For each safe location, the model creates a shortest path tree as shown in Figure 2 with the respective safe locations as the roots of the trees. Well established algorithms such as Dijkstra's algorithm can be used to create the shortest path trees.

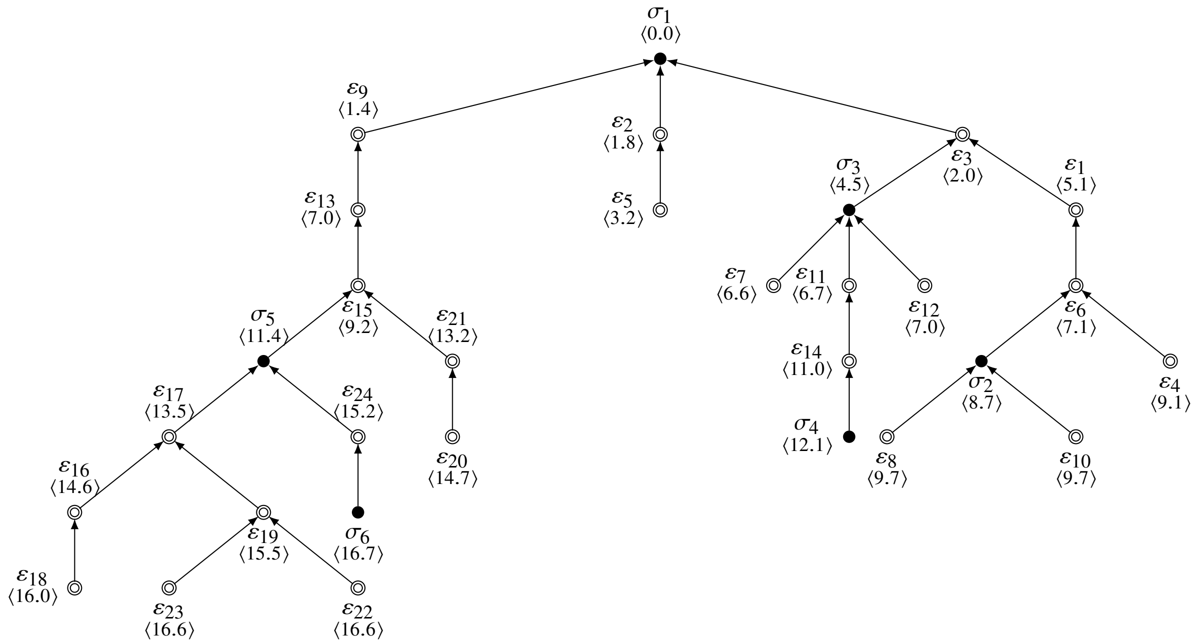

Figure 2. σ_1 Shortest Path Tree

Figure 2 shows the shortest path tree for the safe location σ_1. It can be seen that the tree contains more than just the shortest path distances for each location and σ_1, it also contains all of the shortest paths too. This is confirmed by taking any child node in the tree and repeatedly following the parent edge until the root node is reached.

When the shortest path trees are constructed the shortest path for each evacuation location to any safe location is answered by querying the respective shortest path tree. The set of shortest paths can be represented as a shortest path matrix as shown in Figure 3. Note, the shortest path distances between safe locations are intentionally left out.

The model considers the relative distances of evacuation locations and safe locations over a given shortest path tree this is important as it allows a fair distribution over relative distance between trees (or: safe locations). The values in the shortest path matrix are normalised between 0.25 and 0.75 as shown in Figure 4. Note, the values are normalised so that the lower bound is greater than 0, this is important as a normalisation that allows a relative distance value of 0 would effectively delete the distance component of the heuristic, leading to unfair assignments.

	σ_1	σ_2	σ_3	σ_4	σ_5	σ_6
ε_1	5.1	3.6	5.1	12.7	13.9	18.9
ε_2	1.8	10.5	6.3	13.9	13.2	18.5
ε_3	2.0	6.7	2.5	10.1	11.3	16.3
ε_4	9.1	2.1	5.1	12.1	13.9	18.3
ε_5	3.2	11.9	7.7	15.3	11.8	17.1
ε_6	7.1	1.6	3.1	10.7	11.9	16.9
ε_7	6.6	2.6	2.1	9.7	10.9	15.9
ε_8	9.7	1.0	5.7	11.0	14.5	17.2
ε_9	1.4	10.1	5.9	13.5	10.0	15.3
ε_{10}	9.7	1.0	5.7	9.0	12.7	15.2
ε_{11}	6.7	4.6	2.2	5.4	9.1	11.6
ε_{12}	7.0	7.2	2.5	10.0	6.3	11.6
ε_{13}	7.0	10.0	5.3	8.1	4.4	9.7
ε_{14}	11.0	8.9	6.5	1.1	4.8	7.3
ε_{15}	9.2	11.3	6.6	5.9	2.2	7.5
ε_{16}	14.6	12.7	10.3	2.7	3.2	5.7
ε_{17}	13.5	11.6	9.2	1.6	2.1	4.6
ε_{18}	16.0	14.1	11.7	4.1	4.6	7.1
ε_{19}	15.5	13.6	11.2	3.6	4.1	2.6
ε_{20}	14.7	16.8	12.1	8.9	5.2	2.9
ε_{21}	13.2	15.3	10.6	9.9	6.2	4.4
ε_{22}	16.6	14.7	12.3	4.7	5.2	3.7
ε_{23}	16.6	14.7	12.3	4.7	5.2	1.5
ε_{24}	15.2	17.3	12.6	7.5	3.8	1.5

Figure 3. Shortest Path Matrix

	σ_1	σ_2	σ_3	σ_4	σ_5	σ_6
ε_1	5.1	3.6	5.1	12.7	13.9	18.9
ε_2	1.8	10.5	6.3	13.9	13.2	18.5
ε_3	2.0	6.7	2.5	10.1	11.3	16.3
ε_4	9.1	2.1	5.1	12.1	13.9	18.3
ε_5	3.2	11.9	7.7	15.3	11.8	17.1
ε_6	7.1	1.6	3.1	10.7	11.9	16.9
ε_7	6.6	2.6	2.1	9.7	10.9	15.9
ε_8	9.7	1.0	5.7	11.0	14.5	17.2
ε_9	1.4	10.1	5.9	13.5	10.0	15.3
ε_{10}	9.7	1.0	5.7	9.0	12.7	15.2
ε_{11}	6.7	4.6	2.2	5.4	9.1	11.6
ε_{12}	7.0	7.2	2.5	10.0	6.3	11.6
ε_{13}	7.0	10.0	5.3	8.1	4.4	9.7
ε_{14}	11.0	8.9	6.5	1.1	4.8	7.3
ε_{15}	9.2	11.3	6.6	5.9	2.2	7.5
ε_{16}	14.6	12.7	10.3	2.7	3.2	5.7
ε_{17}	13.5	11.6	9.2	1.6	2.1	4.6
ε_{18}	16.0	14.1	11.7	4.1	4.6	7.1
ε_{19}	15.5	13.6	11.2	3.6	4.1	2.6
ε_{20}	14.7	16.8	12.1	8.9	5.2	2.9
ε_{21}	13.2	15.3	10.6	9.9	6.2	4.4
ε_{22}	16.6	14.7	12.3	4.7	5.2	3.7
ε_{23}	16.6	14.7	12.3	4.7	5.2	1.5
ε_{24}	15.2	17.3	12.6	7.5	3.8	1.5

$\Rightarrow$

	σ_1	σ_2	σ_3	σ_4	σ_5	σ_6
ε_1	0.372	0.330	0.393	0.658	0.726	0.750
ε_2	0.263	0.541	0.450	0.701	0.698	0.739
ε_3	0.270	0.425	0.269	0.567	0.621	0.675
ε_4	0.503	0.284	0.393	0.637	0.726	0.733
ε_5	0.309	0.584	0.517	0.750	0.641	0.698
ε_6	0.438	0.268	0.298	0.588	0.645	0.693
ε_7	0.421	0.299	0.250	0.553	0.605	0.664
ε_8	0.523	0.250	0.421	0.599	0.750	0.701
ε_9	0.250	0.529	0.431	0.687	0.569	0.647
ε_{10}	0.523	0.250	0.421	0.528	0.677	0.644
ε_{11}	0.424	0.360	0.255	0.401	0.532	0.540
ε_{12}	0.434	0.440	0.269	0.563	0.419	0.540
ε_{13}	0.434	0.526	0.402	0.496	0.343	0.486
ε_{14}	0.566	0.492	0.460	0.250	0.359	0.417
ε_{15}	0.507	0.566	0.464	0.419	0.254	0.422
ε_{16}	0.684	0.609	0.640	0.306	0.294	0.371
ε_{17}	0.648	0.575	0.588	0.268	0.250	0.339
ε_{18}	0.730	0.652	0.707	0.356	0.351	0.411
ε_{19}	0.714	0.637	0.683	0.338	0.331	0.282
ε_{20}	0.688	0.735	0.726	0.525	0.375	0.290
ε_{21}	0.638	0.689	0.655	0.560	0.415	0.333
ε_{22}	0.750	0.670	0.736	0.377	0.375	0.313
ε_{23}	0.750	0.670	0.736	0.377	0.375	0.250
ε_{24}	0.704	0.750	0.750	0.475	0.319	0.250

Figure 4. Shortest Path Matrix Normalisation

The Heuristic

The model considers all possible allocations simultaneously, corresponding to the unique row, column pairs in the shortest path matrix. A heuristic is used to sort the possible allocations so that the current best allocation is included in the flood evacuation plan.

We introduce the following notation to describe the new heuristic. Let ε_i represent the i^{th} evacuation location and let σ_j represent the j^{th} safe location. Let an allocation between ε_i and σ_j be represented by $\varepsilon_i \mapsto \sigma_j$. The capacity component weight for a given allocation is represented as $C_{\varepsilon_i \mapsto \sigma_j}$. The distance component weight for a given allocation is represented as $\mathcal{D}_{\varepsilon_i \mapsto \sigma_j}$. The sort weight for a given allocation is represented as $\mathcal{W}_{\varepsilon_i \mapsto \sigma_j}$. The normalised distance of an allocation is denoted by $NormDist_{\varepsilon_i \mapsto \sigma_j}$. The population at a given evacuation location ε_i is denoted by Pop_{ε_i}. The capacity of a given safe location σ_j is denoted by Cap_{σ_j} and the vacancies at a given safe location σ_j is denoted by Vac_{σ_j}.

$$C_{\varepsilon_i \mapsto \sigma_j} = \begin{cases} Pop_{\varepsilon_i} & \text{if } Vac_{\sigma_j} < Pop_{\varepsilon_i}, \\ Pop_{\varepsilon_i} / Vac_{\sigma_j} & \text{otherwise.} \end{cases} \tag{1}$$

$$\mathcal{D}_{\varepsilon_i \mapsto \sigma_j} = Pop_{\varepsilon_i} \cdot NormDist_{\varepsilon_i \mapsto \sigma_j} \tag{2}$$

$$\mathcal{W}_{\varepsilon_i \mapsto \sigma_j} = (\mathcal{D}_{\varepsilon_i \mapsto \sigma_j} + C_{\varepsilon_i \mapsto \sigma_j})^2 \tag{3}$$

The model considers all allocations simultaneously and sorts them on the sort weight $\mathcal{W}_{\varepsilon_i \mapsto \sigma_j}$. The current minimal allocation $\varepsilon_i \mapsto \sigma_j$ is added to the flood evacuation plan. Allocations that remain and contain ε_i are destroyed as the mapping has been satisfied. The process repeats until there are no more allocations to consider.

The capacity component in Equation 1 increases the selection pressure on allocations that map to safe locations with more vacancies. The distance component in Equation 2 increases the selection pressure on allocations that map to nearer safe locations. Finally, the sort weight is used to combine the pressures. This explains the heuristic and its use in the selection process of generating a flood evacuation plan. The model must employ a new technique to distribute evacuees from a single evacuation location to several different safe locations.

Population Division

In Figure 1 the population at each evacuation location is given in brackets below its label, this value is potentially large and without a way to divide the population between different safe locations it can be difficult to distribute the population to safe areas that are nearby. To solve this problem, the model employs a novel approach, at each evacuation location create new incident vertices with an edge distance of 0.0 and move the population from the evacuation location into the new vertices, as shown in Figure 5. The smallest population of all evacuation locations provides an upper bound for the size of the divided off populations. Then apply the model as described, the new vertices can be allocated to different safe locations.

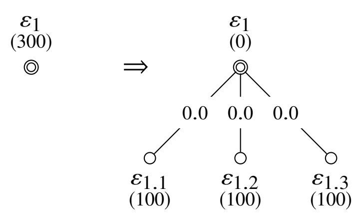

Figure 5. Population Splitting

The model as applied to the case study creates the evacuation plan as shown in Figure 6. Note, some populations are split between different safe locations.

$$
\begin{array}{lll@{\qquad\qquad}lll}
\varepsilon_1 & \Rightarrow & \sigma_1\langle 700.0\rangle & \varepsilon_{13} & \Rightarrow & \sigma_1\langle 200.0\rangle\ \sigma_3\langle 200.0\rangle\ \sigma_5\langle 50.0\rangle \\
\varepsilon_2 & \Rightarrow & \sigma_1\langle 400.0\rangle & \varepsilon_{14} & \Rightarrow & \sigma_4\langle 750.0\rangle \\
\varepsilon_3 & \Rightarrow & \sigma_1\langle 150.0\rangle\ \sigma_3\langle 250.0\rangle & \varepsilon_{15} & \Rightarrow & \sigma_5\langle 600.0\rangle \\
\varepsilon_4 & \Rightarrow & \sigma_2\langle 200.0\rangle\ \sigma_3\langle 400.0\rangle & \varepsilon_{16} & \Rightarrow & \sigma_4\langle 150.0\rangle\ \sigma_5\langle 500.0\rangle \\
\varepsilon_5 & \Rightarrow & \sigma_1\langle 700.0\rangle & \varepsilon_{17} & \Rightarrow & \sigma_5\langle 850.0\rangle \\
\varepsilon_6 & \Rightarrow & \sigma_2\langle 850.0\rangle & \varepsilon_{18} & \Rightarrow & \sigma_4\langle 600.0\rangle \\
\varepsilon_7 & \Rightarrow & \sigma_3\langle 450.0\rangle & \varepsilon_{19} & \Rightarrow & \sigma_6\langle 800.0\rangle \\
\varepsilon_8 & \Rightarrow & \sigma_2\langle 600.0\rangle & \varepsilon_{20} & \Rightarrow & \sigma_6\langle 700.0\rangle \\
\varepsilon_9 & \Rightarrow & \sigma_1\langle 650.0\rangle & \varepsilon_{21} & \Rightarrow & \sigma_1\langle 200.0\rangle\ \sigma_6\langle 300.0\rangle \\
\varepsilon_{10} & \Rightarrow & \sigma_2\langle 750.0\rangle & \varepsilon_{22} & \Rightarrow & \sigma_6\langle 650.0\rangle \\
\varepsilon_{11} & \Rightarrow & \sigma_3\langle 500.0\rangle & \varepsilon_{23} & \Rightarrow & \sigma_6\langle 450.0\rangle \\
\varepsilon_{12} & \Rightarrow & \sigma_3\langle 800.0\rangle & \varepsilon_{24} & \Rightarrow & \sigma_6\langle 600.0\rangle
\end{array}
$$

Figure 6. Flood Evacuation Plan

DISCUSSION

The optimality of solutions generated by evacuation planning models is necessary, due to the direct impact it has on emergency evacuation plans. Models that offer a guarantee of optimality are desirable as they help to reduce evacuation times. In this paper, a new heuristic evacuation model is proposed as an alternative to stochastic approaches to help mitigate some of their associated disadvantages.

The optimality of a solution is difficult to measure, one theme which is common in all literature is that evacuation plans should minimise the evacuation time. In other words, minimising the total distance that each evacuee has to travel during an evacuation. This measure does not take into account outside pressures that compete for the same resources. As a result, the plans generated may also be suboptimal. At this moment in time this limitation is not exclusive to this model, and it is believed that the impact may be reduced as this model can produce updated plans during the flooding event.

This work is part of an ongoing UK research project, and more is expected to come from this research shortly. The next step is to develop the model and test it under many different conditions, to evaluate the current design. It is also planned to test the model on large-scale real-world data to investigate the model further.

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Protection Models For Complex Critical Infrastructures

Process modelling of physical and cyber terrorist attacks on networks of public transportation infrastructure

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ABSTRACT

Recent events have demonstrated the vulnerability of IT-systems of different companies, organisations or even governments to hacker attacks. Simultaneously, information technologies have become increasingly established and important for institutions of various branches. With respect to modern terrorism developments, cyber-attacks may be used to physically harm critical infrastructures. This leads to a new dimension of cyber-attacks called "terrorist cyber-attacks".

This research-in-progress paper aims to develop a process model for data acquisition and support of decision making that seeks to enhance the security of public transportation in the context of counterterrorism. Therefore, a generic process model for terrorist cyber-attacks – produced in the research project RE(H)STRAIN[1] – is introduced as a basis for a decision support system (DSS). In the future, such models could improve the decision process by comparing the effectiveness of different security measures.

Keywords

Cyber-attack, (counter-)terrorism, process modelling, decision support, critical infrastructure

INTRODUCTION AND RESEARCH QUESTION

As a result of increasing interconnection of systems and progressing digitalisation of processes, there is a rising dependence on IT systems across all industrial sectors including public transport. Analogous technology has been replaced by computerised (railway) control centres and in many cases e.g. railway signals and switches are operated automatically and remote-controlled (Tschirner et al. 2014; Kawalec and Rżysko 2016). IT support is used to control complex train systems (Chen et al. 2015), especially for high-speed railway traffic. Future railway developments will make signalling on the tracks obsolete because trains will receive the necessary control commands directly via mobile communication services like GSM-R (cf. European Train Control System). This will enhance the density of train succession, create higher speed possibilities (Stamm 2011), but also lead to an even higher dependence on IT systems and networks.

[1] "Resilience of the Franco-German Highspeed Train Network", Research for Civil Security funded by the German Federal Ministry for Education and Research and the Agence Nationale de la Recherche (France),Grant No. 13N13786 to 13N13790

In addition to IT utilisation, there is an increasing risk through cyber threats. In recent years, cyber-attacks have become more relevant by increased occurrence and induced damages, even such as data theft (World Economic Forum 2012, 2016). This paper discusses the question how basic characteristics of physical terrorist attacks are transferable to the processes of terrorist cyber-attacks.

In particular, the focus will be on high speed traffic, since national high-speed trains are flagships of the national transportation services, technology carriers, and thus are attractive targets for terrorist attacks (Strandberg 2013).

Very recent cyber-attacks were without consequences (McGoogan and Willgress 2016; Boyle 2016), but they showed the general ability of attackers to access IT-systems of transport infrastructure. It can be assumed that it is only a matter of time before cyber-attacks will cause physical damage to certain structural elements – a similar development were the Stuxnet cyber-attacks in 2007 to 2010 (Subhash Lakshminarayana et al. 2016; Bambauer 2014).

In the light of the above, the main idea of this research in progress paper is to create a better understanding of attack sequences through the use of process models. So called points of intervention (POIVs) where security measures can come into effect have been defined for attack processes. These POIVs pose a connection between the attack process on the one and security measures on the other hand. The goal of this paper is to present an outlook of how both, the process models as well as the POIVs as connective elements could be useful for developing a DSS that seeks to give recommendations regarding the implementation of the most effective security measures for certain POIVs.

Furthermore, the research will show the necessity of a combined approach for countering physical and cyber terrorist threats.

FORMULATION OF HYPOTHESIS: TERRORIST

There is no internationally or legally binding definition of terrorism. However, various sources agree that the term terrorism describes violent, illegal action of one or more individuals against society or other targets. The aim of these actions is to influence the political and social behaviour according to the terrorist's objective by creating fear and terror (18 U.S.C. § 2331; Department of Defense 2010; Department of Homeland Security 2006). Typical terrorist objectives can originate from ideological, political or religious motives but divergent or mixed motives are not excluded.

A multitude of different weapons and an equally high number of attacked assets can be observed for terrorist attacks that have been committed to date. Based on the analysis of previous attacks, which was conducted in the context of the research project RE(H)STRAIN, it was documented that railway traffic is an attractive target for attackers. This attractiveness is unaffected by the used weaponry, because the subjective impact of attacks on society (passengers) is high, due to the daily use of the attacked target. Examples for this effect are the attempted gun attack in a Thalys train in 2015, the attacks on the Metro in Brussels in 2016 or London in 2015, the knife attack in a German regional train close to Wuerzburg in 2016 or the axe attack in Germany at Duesseldorf train station (BBC News 2015, 2016; Gray 2015; Oltermann and Rawlinson 2016; BBC News 2017).

All these examples as well as additional attacks have two fundamental observations in common. Firstly, the attackers' intention, to create fear and terror, is rather similar despite the wide range of differing motives. Secondly, weapons were used to cause physical damage to people or tangible objects. Accordingly, the subsequent axioms on behaviour and intention of terrorists can be defined. They will serve as working hypotheses for this research.

Table 1. Working hypotheses "terrorist"

1.	All terrorists aim to create a maximum of fear and terror in the targeted society. To achieve this goal, major damage to persons and/or property is done, independent of the chosen weapon.
2.	According to the first axiom and because terrorists seek suitable conditions to execute their attack, similar intentions of terrorists lead to a comparable process of planning and operating, regardless of the chosen weapon or the selected target/asset.

PROCESS MODELLING AS AN OPPORTUNITY TO ASSESS PHYSICAL TERRORIST ATTACKS

Based upon the hypotheses in table 1, it can be proven that neither the exact place of an attack nor the precise weapon are decisive for the evolving process steps – especially during the phase of preparation. The level of abstraction in the generic process model neglects the choice of weapon, the choice of asset as well as the terrorists' capability – and merely focusses on the modus operandi. This leads to a facilitation of the real processes but is useful in developing a generic process model.

Of course, parameters such as chosen weapons and assets as well as the terrorist's capability to carry out an attack influence the probability of detection and the extent of damage, e.g., different numbers of victims or different time of recovery; however, their impact on the processes of planning or preparation is limited. Consequently, this process model may serve as a theoretical basis for further research. Assuming the rightness of the hypotheses, attacks can be described in this abstract process model, which can be further applied to all kinds of terrorist attacks. To develop a reliable process model, various iteration steps had to be taken.

The process model in figure 1 incorporates all possible steps of the attacker, including the planning and execution of an attack. The developed process for physical attacks is based upon research results of previous projects (RiKoV[2]) as well as interviews with experts with a scientific background. In its current state, the process model does not account for the adaptability of the attackers. For example, the terrorists could try to avoid the security measures that they are aware of or integrate them in their planning process, so that they are not effective anymore.

All measures that might interrupt the attack process are referred to as measures of successful prevention. They deter, detect, or neutralise attacker or weapon. The points where these measures come into effect and interrupt or influence the attack process are referred to as "points of intervention" (POIVs) in the course of the project RE(H)STRAIN. The effect of different security measures at these POIVs was discussed within the project as well as with experts. By using such POIVs, it is possible to determine whether security measures are applicable or not for each step in the planning and execution phase.

Currently, these POIVs are linked to an existing security measure database that was developed for public transportation systems by the joint research project RiKoV (Brauner 2017). It contains additional information about current and future security measures for the prevention and mitigation of physical attacks. Referring to Brauner et al. (2015), the combination of a structural interview guideline for experts and a scenario process model in a semi-quantitative assessment methodology allows estimating the effectiveness of single and combined security measures in each POIV. The developed process model in RiKoV is able to assess physical attacks on public transportation systems and to estimate the change of vulnerability in the context of different security designs. The new process model presented in this paper will become a framework to assess security designs for cyber-attacks that can have hidden or obvious effects (damages). Therefore, it can be used in risk and crisis management systems to improve decision-making by end-users. In the following section, the development of a process model for terrorist cyber-attacks is examined.

[2] Risks and costs of terrorist threats to railbound public transport (funded by the German Federal Ministry of Education and Research, Grant-No.: 13N12305)

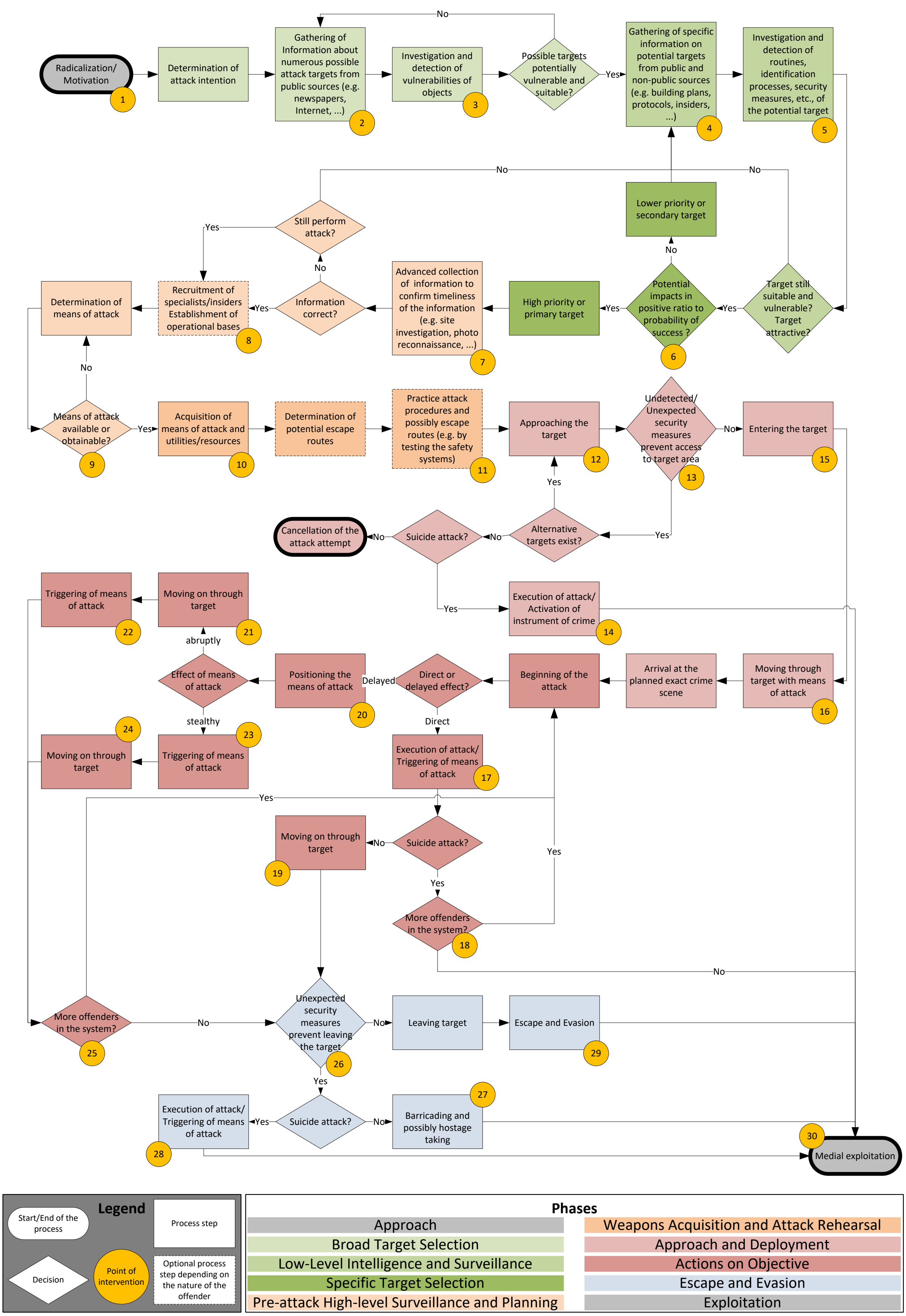

Figure 1. Attack process model (physical attack)

TRANSFER TO CYBER-ATTACK PROCESSES – FORMULATION OF HYPOTHESES: CYBER TERRORIST

Both frequency and dimension of cyber-attacks have increased in recent years. For this reason, we assume that this form of attack will be used by terrorists or has already been used, even if it has not been specifically proven. This includes classic cyber-attacks to disturb or destroy IT systems as well as attacks using IT systems to cause physical consequences (e.g. train crashes). The intention of a terrorist attack follows the similar heuristic behaviour explained in table 1.

Generally, cyber-attacks can roughly be divided into five different steps. The first step comprises the gathering of intelligence using techniques such as social engineering. The initial intrusion of the asset, step two, is followed by a phase of horizontal spreading to gain command and control in the targeted system, which can take up to several months. The intrusion becomes visible during the final steps, the escalation of privileges that eventually leads to the execution of the intended attack. Examples for this strategy are the already mentioned Stuxnet cyber-attacks from 2007 to 2010 (Subhash Lakshminarayana et al. 2016; Bambauer 2014) or the ongoing BlackEnergy-attacks against the Ukrainian power grid (Industrial Control Systems Cyber Emergency Response Team and Department of Homeland Security 2017).

There is no common international definition for cyber terrorism, similar to the lack of exact definitions for terrorism. The sources that mention the term at all often use definitions for terrorism, enhanced by including that cyber terrorism is a form of terrorism using the Internet as a weapon, i.e., using Internet technologies to attack computer systems (German Federal Ministry of the Interior 2017; Combs and Slann 2007; Federal Bureau of Investigation 2007; Tafoya 2011; United States Army Training and Doctrine Command 2007; Department of Defense 2016; Department of Homeland Security 2013). The sources emphasise that cyber-attacks can take place combined with conventional, i.e., physical attacks. This has to be considered by setting up security designs. The hypotheses of table 1 can be adapted to cyber-attacks as follows:

Table 2. Working hypotheses “cyber terrorist”

1.	All terrorists aim to create a maximum of fear and terror in the targeted society. To achieve this goal, major damage to persons and property is done, independent of the chosen weapon.
2.	According to the first axiom and because terrorists seek suitable conditions to execute their attack, similar intentions of terrorists lead to a comparable process of planning and operating, regardless of the chosen weapon or the selected target/asset.
3.	The goal of each cyber terrorist is to make the cyber-attack real, i.e., according to hypothesis one, creating physical damage by using IT systems as a weapon.
4.	The combination of a physical attack and a conventional cyber-attack is possible.

TRANSFER OF THE PHYSICAL PROCESS MODEL TO CYBER TERRORIST ATTACKS

Due to the similarity of the hypotheses of physical and cyber terrorist attacks, we assume that the approach to create a process model can be transferred to cyber-attacks. In addition, three scientific and industrial experts confirmed this transfer as being possible. While two of the experts stated that the use of process modelling is an uncommon method in the sector of IT systems security, all agreed on the general transferability (Lo Iacono 12/5/2016; Kuklok 12/28/2016).

Based on the hypotheses, a generic process model was developed for cyber terrorist attacks, independent of weapons and targets. This enables the development of POIVs. As in the model for physical attacks, the adaptive capabilities of the attacker are not taken into consideration.

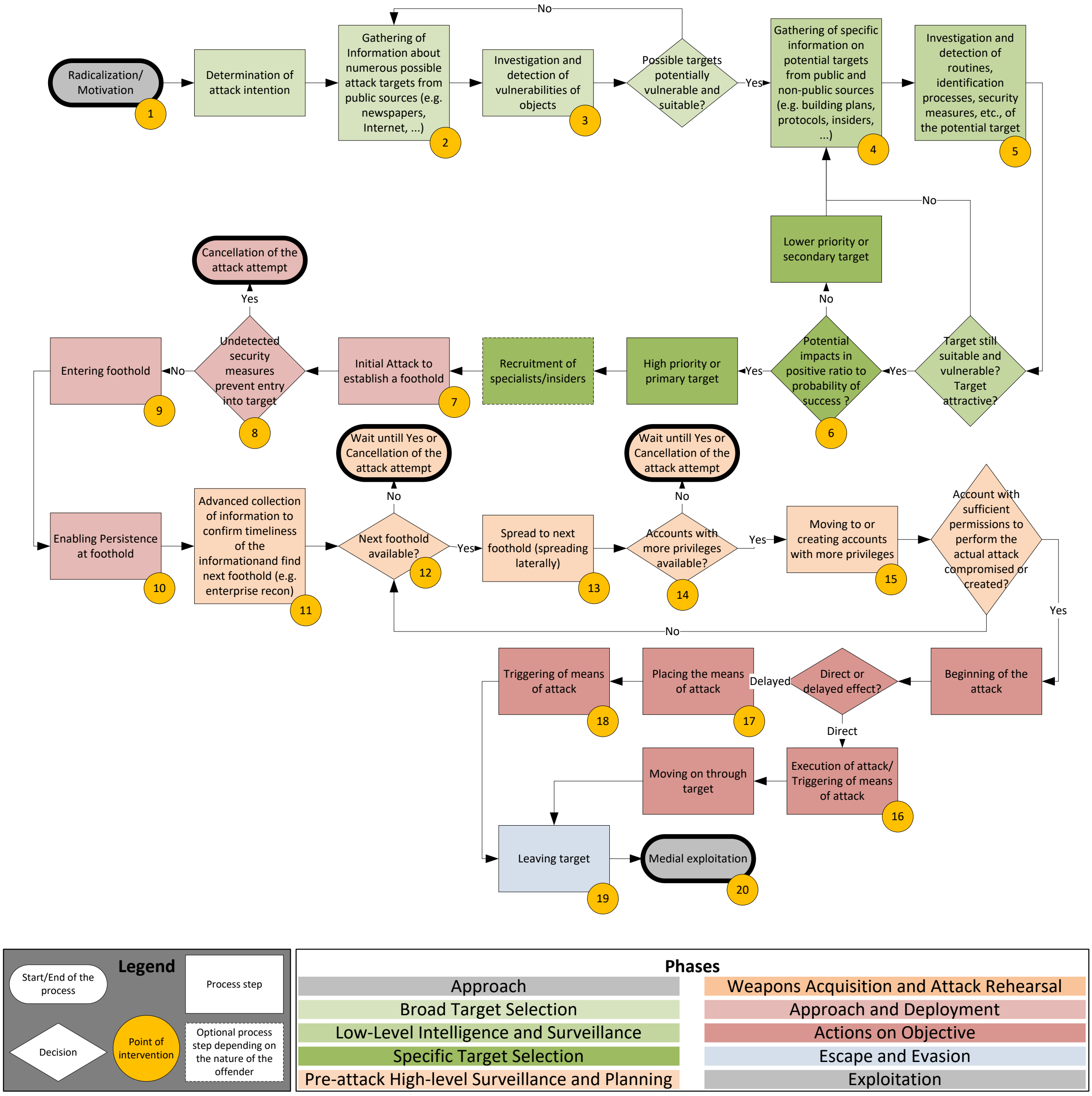

Figure 2. Attack process model (cyber-attack)

These POIVs depict potential places within the process model where security measures can come into effect. As mentioned above, intervention in this context means that the attack is either interrupted or influenced in a favourable way from a counter-terrorist-point of view. That raises the question, which of the multitude of various security measures is most likely to influence or interrupt the attack process most effectively? In order to answer this question, an immense quantity of information has to be considered and processed. The subsequent section explains how the process model could contribute to providing recommendations to potential end-users (e.g. station service providers). Furthermore, it is discussed, which data could additionally be required for the future development of a DSS that deals with the implementation of security measures.

ASSESSMENT OF REASERCH IN CONTEXT OF DECISON SUPPORT PERSPECTIVES

In a world of growing complexity and interdependency of business and industrial operations, decision support systems have gained popularity within various industrial branches over the last few years (Ishizaka and Nemery 2013). In general, such systems aim to help decision-makers assess complex – even sparsely known – situations (Sprague 1980; Valverde 2011). In order to do so, DSS condense and organise information that was usually extracted from one or more databases. The outcome is valuable – meaning relevant – knowledge, which is useful to estimate and evaluate the multifaceted consequences of different complex action alternatives (Valverde 2011). Thus, the ranking of different alternatives can be considered a form of decision support. Weighting different alternatives with help of different factors and taking into account a large amount of information seeks to, among others, enhance business performance – meaning in this context to enhance a system's reaction to disruptions. Of course, evolving expenses for the various forms of enhancement need consideration as well. Comparing the costs for different organisational or technical security measures while also considering their potential effectiveness within an existent system and giving a recommendation about the most efficient solution could serve as an example.

In the field of risk and crisis management, decision-makers usually consider various criteria when making their choices. For example, when assessing multifaceted vulnerabilities or predicting probabilities of the occurrence of certain events. In this context, there are different phases or situations where decision support tools can be helpful. Different projects in the past were concerned with decision support issues in the context of emergency response (e.g. SOCIONICAL[3], STEP[4] and many more). During planning phases, DSS can support the ranking of different assets regarding their vulnerability or their importance for an organisation or a society. A compilation edited by Gheorghe (2005) describes the use of DSS for risk and vulnerability management – though mainly in the context of industrial risks (Spadoni and Bonvicini 2005).

The focus of this paper is to provide support during planning phases (risk assessment). Although a process model that includes POIVs and a list of security measures forms a solid informational basis, it does not deliver sufficient data for a DSS. Providing a mere summary of available security measures is not enough. Therefore, the effectiveness of each security measure, its respective costs as well as the possibility of implementation, need consideration, too.

As the effectiveness of security measures is an important factor in the context of decision support in the examined field (Adler and Fuller 2009; Brauner 2017), a qualitative rating (*high*, *low*, *none*) for each security measure will be added to the database. This rating refers to the security measures' effectiveness in relation to a certain attack process step. Especially from an economic point of view, costs and required effort for the implementation of security measures are decisive factors in the decision process. Adding these aspects to the process model will improve the groundwork for a DSS.

In addition to the qualitative approach outlined above, agent-based simulations as well as real large-scale exercises can assess the effectiveness of security measures more precisely. These methods have the advantage that they produce large amounts of data for evaluating and comparing security measures under different conditions. On the downside, simulations require large amounts of information to be processed and large-scale exercises are time-consuming and costly. Making use of the qualitative rating leads to a less precise, but quick assessment that produces transparent and comprehensible results.

The approach presented above is not exhaustive. The paper is supposed to outline an idea that – if further developed – could become a DSS. As presented in the previous section, the process model for terrorist cyber-attacks derives from the model for physical attacks. Three experts with scientific research and industrial background have verified its general transferability but as some expressed their doubts regarding the universal applicability of the individual steps, the process model is currently still in the process of validation. Nevertheless, the holistic and universal model of attack process steps and the collection of available security measures are the basis for offering decision support in the context of identifying additional protection for IT-systems regarding terrorist attacks. With the process model as a basis and if all factors mentioned above are considered in a database, decision-makers will be able to make choices regarding most suitable and most effective security measures for their individual needs.

CONCLUSION, OUTLOOK AND FURTHER RESEARCH

The initially formulated research questions in this paper can be answered as follows: According to different experts, the basic characteristics of physical terrorist attacks can be transferred to cyber terrorist attacks. The development of attack processes is sparsely spread within the IT-community and possibly error-prone. A statement can be made about how effective security measures are for each process step. The quality of such statements is dependent on the quality of the available databases of security measures. It is difficult to depict the uncertainty regarding the different possible terrorist reaction to security measures or unforeseen obstacles. The recurring re-evaluation and continuation is essential for the successful use of the presented approach.

The developed decision support framework will be validated by end-users. In addition, future developments will be used to continuously improve and adjust the process models. Through this, the inclusion of new events (of currently unknown dimensions) of physical and cyber threats will be ensured and will contribute to the process

[3] http://www.socionical.eu/

[4] https://www.fit.fraunhofer.de/de/fb/risk/projects/step.html

of decision-making regarding suitable security measures. It is important to keep in mind the discrepancy between reality and model that results from the abstraction of real processes. Additionally, the database of security measures will be extended and maintained to keep it up to date and expandable.

The previously introduced hypotheses have to be discussed concerning the validation of changing terrorist behaviour in the future. Recent attacks support the assumptions, but new, yet unknown forms of terrorism could question these. Future research will be executed on new modi operandi including the combination of physical and cyber-attacks. To depict such attacks, parts of both process models will be fused. The processes of planning and preparing both – physical and cyber-attacks – might be comparable and only divide up into separate processes during the execution of the planned attack. This approach could possibly contribute to the basis for a holistic risk management strategy.

An adjustment of the process models based on the hypotheses may be necessary. Furthermore, the models should be validated and constantly improved with additional expertise. Even the development of a DSS based on the first results of this research in progress paper has to be critically evaluated with regard to its feasibility.

For further research, it is planned to enrich the decision support framework with railway station relevant and specific data. This could allow the inclusion of further and more precise factors of vulnerability and therefore enable a more suitable and profound decision-making. Additionally, a concrete statement concerning the practicability and feasibility of security measures could be possible. Another point is the implementation of the terrorists' reaction to security measures, which could also be depicted by enriching the presented process model with simulation data.

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An Approach for Analyzing the Impacts of Smart Grid Topologies on Critical Infrastructure Resilience

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ABSTRACT

The generation and supply of electricity is currently about to undergo a fundamental transition that includes extensive development of smart grids. Smart grids are huge and complex networks consisting of a vast number of devices and entities which are connected with each other. This fact opens new variations of disruption scenarios which can increase the vulnerability of a power distribution network. However, the network topology of a smart grid has significant effects on urban resilience particularly referring to the adequate provision of vital services of critical infrastructures. An elaborated topology of smart grids can increase urban resilience. In this paper, we discuss the role of smart grids, give research impulses for examining diverse smart grid topologies and for evaluating their impacts on urban resilience by using an agent based simulation approach which considers smart grid topology as a model parameter.

Keywords

Smart Grids, Urban Resilience, Agent Based Simulation, Critical Infrastructure Protection, Decision Support.

INTRODUCTION

The deployment of intelligent metering for developing smart grids as a lynchpin for the ongoing Energiewende is speeding up. In the most EU member states the smart meter roll-out has already started. It is expected that almost 72% of the European consumers will have a smart meter for electricity by 2020 (European Commission, 2014). The roll-outs are accompanied by critical public debates which are essentially related to fundamental security worries and the generally noticed increased vulnerability due to undesired manipulations from external parties, see for example (Aloul et. al., 2012; Goel et al., 2015; Mo et al., 2012; Neuman and Tan, 2011). In view of these debates, unfortunately the benefits are not recognized sufficiently and there is still a need for research on the functionalities and the utilization of smart grids w.r.t. critical infrastructure (CI) protection and urban resilience.

In light of this demand, we would like to open up the attention for the urban resilience implications of smart grid topologies. The new possibilities of communication between the customers, grid components, and the grid utilities due to the introduction of smart meters allow to bridge the gap between isolated grid operation procedures and crisis response activities of CI providers and disaster management authorities. Despite the noteworthy efforts in the development of smart grids, the resilience implications of smart grid topologies are still not enough appreciated in practice and research and, therefore, request a more precise observation.

In this paper, we address this request by introducing our progressing development of an agent based decision support approach which should enable to simulate and compare different smart grid topologies, and inter alia reveal not obvious interdependencies between CIs or CI components. Focusing on the German circumstances regarding the technical distribution grid operation and the legal and practical regulations on disaster management, the results should enable assessments of the resulting level of CI service supply in an urban area. Whether the shortage or cut-off is caused by grid instability or infrastructure destruction, the simulations should allow to identify more and less robust smart grid topologies, and to find even new and better ways of managing potential risks of CI service disruptions. A main objective of our research is to obtain an enhanced understanding of how the types of smart grid topologies influence urban resilience which itself may be utilized to support the design and development of robust smart grids in urban areas in Germany.

This paper is structured as follows. First we give a short definition of urban resilience then we shed some light on advanced principles of power outage response activities and equilibrium states. Taking these considerations into account we give a short technically flavored survey on smart grids and highlight certain topological degrees of freedom in the context of urban resilience. Subsequently we describe an agent based approach for simulating CIs or CI components as a tool for assessing urban resilience and supporting decision making. Since the models of agent based simulations may be changed by varying model parameters the aforementioned topological degrees of freedom may be recognized as model parameters.

URBAN RESILIENCE AND CRITICAL INFRASTRUCTURES

There is no prevalent definition of the term "urban resilience" although there are many definition approaches available e.g. (Bhamra et al., 2011; Chelleri, 2012; Leichenko, 2011; Meerow et al., 2016). Meerow et al. (2016) proposed a more inclusive and flexible definition approach which allows an integration of many risk facets and coping mechanisms. In this work, we emphasize the urban resilience aspect of a continuous supply of CI services during crisis situations. CI services such as the supply of electricity, drinking water, and health care provide vital services for the population, thus disruptions or failures of these services are hazardous and can lead to injuries or even losses of life, property damages, social and economic disruptions or environmental degradations (United Nations International Strategy for Disaster Risk Reduction, 2015). Following the basic definition proposed by Meerow et al., we recognize the ability of cities to maintain or rapidly return to a desired level of CI services in the face of disruption scenarios as one important aspect of urban resilience. As mentioned before, our research aims at providing decision support for the development of smart grid topologies. This implies a capability that can also be understood as a mechanism to build resilience. The findings should inter alia enable to technically adapt, change, and quickly transform urban systems.

PRINCIPLES OF POWER OUTAGE RESPONSE ACTIVITIES

Depending on the magnitude, electricity system failures have different effects on the electricity supply and thus on the continuous supply of CI services. Failures with the potential for cut-offs can be generally distinguished between missed load balancing and physical destructions of electrical devices in the grid system. Corresponding to the initial causes of the failures, there are multiple measures available to respond to potential or concrete power outages.

Grid and market based measures are pooled in the so called measure cascade (VDN, 2007; bdew and VKU, 2013; see also the technical norm VDE-AR-N 4140) that, however, does not include measures from potentially affected consumers and disaster management authorities. From the disaster management perspective, the shortage or the cut-off of electricity is the most severe scenario. In such situations it is possible to decouple certain consumers from the grid to ensure grid stability. During this so called load reduction procedure a prioritized electricity supply for critical consumers is ensured which is already applicable in some countries see also (Münzberg et al., 2013). Another possibility is the building of isolated operating islands, where a region is disconnected from a grid to ensure a continuous supply of all or at least some consumers who are situated in the island.

Furthermore, potentially affected CI providers and disaster management authorities also possess capabilities to keep a certain amount of CI services running for a certain time. CI providers usually have coping capacities in the form of enhanced safety storages, larger tanks and emergency back-up generators. In addition, some processes are timely flexible and it is possible to reschedule, extend or delay their realization while keeping the core business of a CI service running – this is also known as process flexibility and load shifting. Furthermore, the disaster management authorities have a very limited amount of mobile emergency generators and other resources that can be used to assist CI providers in keeping their business running.

So far, the response activities of the grid utilities, the CI providers, and the disaster management authorities are not properly concerted, integrated and interlinked. There is research dealing with inter-organizational issues in emergency management during power outages see (Wiedenhöfer et al., 2011; Reuter, 2013).

A basic objective for a better integrated power outage response is the achievement of an equilibrium with regard to the available electricity and the consumers' capability and demand. For an introduction and an overview about equilibria in the context of urban resilience see (Holling, 1996; Meerow et al., 2016).

The optimal equilibrium under normal conditions allows a satisfaction of all electricity requests from all consumers. However, crisis situations are inherently characterized by a loss of system balance. Depending on the request for a stable and safe grid operation, the amount of available electricity, the still available possibilities to distribute electricity, and the customers' capabilities and demands it may be possible to reach other emergency equilibria. These equilibria might disappoint some consumers but allow a - sometimes timely limited - supply of other consumers. This mechanism can be applied to prioritize CI services and keep them supplied during a power shortage situation. Corresponding to the given situation, multiple equilibrium states with different impacts on the population, CI services, and other consumers are imaginable. In the sense of urban resilience, the objective of integrated power outage response activities should be to reach the best possible equilibrium in which the least damage to or restrictions of CI services occur.

An important equilibrium status is defined by the minimum societally accepted and lowest reasonable level of CI services. This equilibrium of "minimum level of CI service supply" ("Mindestversorgung") represents a status in which no risks or further risks occur. It implies a safe shutdown status following a reactive failing-safe principle through maintaining an emergency supply using the available coping capacities. In Germany, there is an ongoing debate about the determination of this status which is methodologically related to the definition of "protection target levels" ("Schutzziele"). Protection target levels mark supply objectives for specific CI facilities or a group of CIs of the same type to ensure basic services. For more information on protection target levels see exemplary (Bundesministerium des Innern 2009, 2011a, 2012; Fekete, 2012; Münzberg et al., 2014, 2017A).

An integrated interlinkage of these measures would expand the possible actions to respond to power outages. We therefore propose the definition of successive safety conditions which represent different escalation scales and imply different measures of grid utilities, CI providers, and disaster management authorities. Figure 1 displays the safety conditions and the effects of responses from distribution grid utilities, CI providers, and authorities.

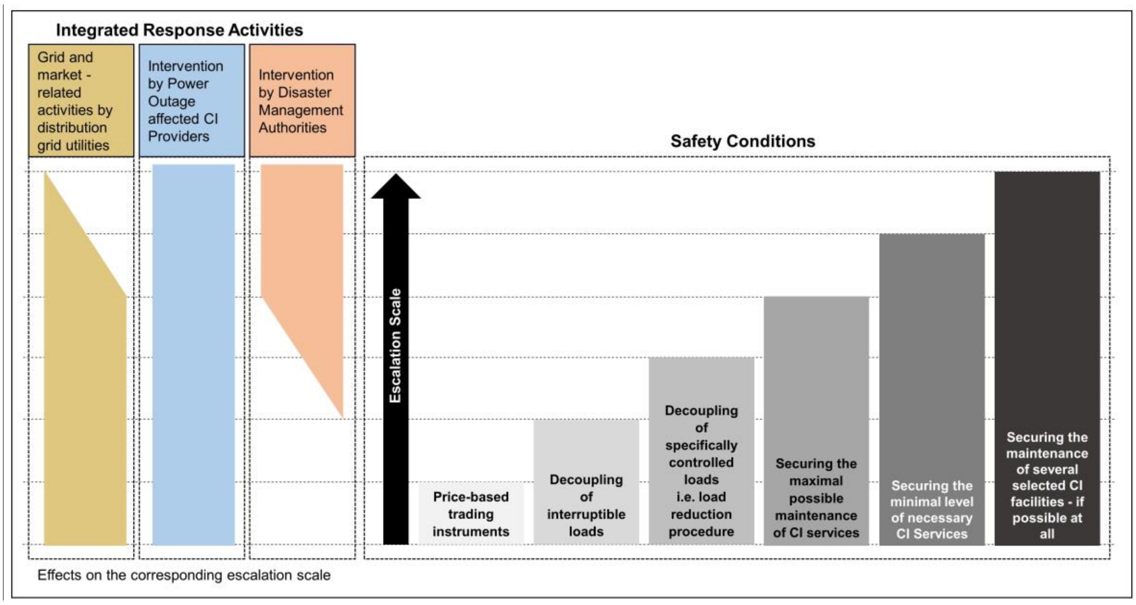

Figure 1. Overview of safety conditions and how integrated response activities of grid utilities, CI providers, and disaster management authorities effect the safety conditions.

The successive safety conditions contain

- price-based trading instruments,
- decoupling of interruptible loads,
- decoupling of specifically controlled loads i.e. load reduction procedure,
- securing the maximum possible maintenance of CI services,
- securing the minimum level of necessary CI Services, and
- securing the maintenance of several selected CI facilities - if possible at all.

Price-based trading instruments are policy and market measures that use economic variables (e.g. markets, price) to provide incentives for market participants to match electricity consumption with generation. It is to be expected that smart meters and dynamic pricing of electricity will play a more important role in the daily usage of electronical devices as today. They will also be used to reduce or eliminate risks in the sense of an enhanced reliable and stable electricity supply. The competence for price-based trading instruments lies within the consumers and the electricity utilities.

In some countries such as Germany, industrial consumers can conclude contracts with electricity utilities which determine interruptible loads. Interruptible loads can be decoupled if it is necessary to stabilize a grid. In return the consumers receive appropriate incentives. Although this measure may be seen as a market-based instrument, it is only used in those emergency situations in which other market-based instruments didn't succeed in stabilizing a grid.

The next escalation step contains a specifically controlled load reduction. As already mentioned, this may include a prioritized and discriminating supply of facilities that provide CI services such as hospitals, dialysis clinics, or general practitioners. If even this measure is not successful, a large-scale power outage would be unavoidable.

In this escalation stage, the objective should be to secure the maximal possible maintenance of CI services considering all available opportunities including smart grid topologies that are introduced in detail in the next section.

The next higher escalation stage is reached if the power distribution grid can only ensure the "minimum level of CI service supply". This case implies a strong system disorder that can no longer be handled by grid utilities alone. Such cases basically require high efforts of the affected CI providers, consumers who rely on CI services, and the disaster management authorities in charge.

The highest escalation stage is achieved if even this is not possible anymore. In such cases of fundamental disorder, the objective is to at least maintain several selected CI facilities if this is possible at all.

Each safety condition inherently considers the limited coping capacity of consumers who rely on CI services. The response activities from grid utilities, CI providers, and authorities contain multiple bundles of measures. They cover different safety conditions with different intensities. The coverage and intensity of the measures are illustrated exemplary in Figure 1 by the thickness of the corresponding effect bars.

SMART GRID STRUCTURES

The generation and supply of electricity is currently about to undergo a fundamental transition. Due to the integration of smart meters, the consumers in the classical sense will have the potential and the eligibility to consume, produce and distribute electricity. The therefore necessary smart meters are electronic devices that monitor electricity consumptions and generations and allow two-way communications with other meters. The usage of smart meters necessitates a power grid technology which allows a bi-directional energy and communication flow and which is equipped with the following key features:

- Decentralization: Individuals are allowed to generate and feed in power.
- Load Balancing: The total sum of produced power might exceed the current load/demand or vice versa. However, to keep a stable electricity supply it is important that in-feed and consumption form a equilibrium.

In order to maintain grid stability, smart grid components handle the aforementioned issues with respect to available resources e.g. power storages or by controlling and managing the demands of the costumers. A more detailed description of a smart grid and its components may be found in (Kabalci, 2016; Muscas et. al., 2015).

If we think about smart grids in the context of cities we are dealing with a huge and complex network consisting of a vast number of devices and entities which are connected with each other. Hence a smart grid must incorporate an Advanced Metering Infrastructure (AMI) that leverages enhanced layers of network technologies i.e.

- Private networks like Home Area Network (HAN), Industrial Area Network (IAN), Building Area Network (BAN), and
- Wide Area Networks (WAN) which comprise Local Area Networks (LAN) like Neighborhood Area Networks (NAN) and Field Area Networks (FAN).

A private network forms a command-and-control layer within a customer's premise which connects sensors and other appliances. A LAN defines an interface between smart meters and distribution substations utilizing gateways and field components. WAN is a network of power utility assets e.g. power plants, substations, distributed storages etc.

A smart grid construed as a distribution grid fundamentally relies on a rigorous Distribution Management

System (DMS) in order to avoid power outages and maintain grid performance. The architecture of a DMS allows a partitioning into several locally arranged and interconnected operation centers which themselves may be considered as local DMSs. A precise and secure operation of an Energy Management System (EMS) of a smart grid heavily depends on the degree of accuracy of the transmitted quantities of interest - so called Concentrators, integrated in LANs, aggregate data from smart meters and relay them to local DMSs.

So far we gained a rough impression of the massive complexity of a smart grid in terms of network layers and components. On the one hand the two-way communication and power flow architecture opens new possibilities like integrating and controlling distributed power generation and supply resp. on the other hand such a heterogeneous and complex network increases vulnerability of the energy system which is clearly comprehensible by the following example:

Corrupted data - as depicted in the following paragraph - sent by a concentrator to a DMS, e.g. over- or underestimated voltage profiles, might erroneously cause the EMS ask for more or less power production or supply respectively. This could potentially lead to further unwanted cascading effects within the distribution grid escalating into power outage.

Smart grid instabilities may be caused by system induced failures. Referring (Aloul et. al., 2012), many components of a smart grid are located not on the utility's premise and are therefore prone to physical damage. Since IT systems are relatively short lived it is quite likely that outdated devices are still in service e.g. anti-virus software may be deprecated or hardware components may not comply with the latest requirements. Furthermore, the great number of devices are potential entry points for malicious cyberattacks like,

- malware spreading which may infect smart meters or other devices and can add or replace functions and disseminates,
- injecting false information by faking sensitive smart meter that can cause wrong decisions, and
- Denial-of-Service attacks by manipulating IP protocols that can delay, block or corrupt the transmission of information in order to make smart grid resources unavailable.

The rationale for designing a smart grid is to consider it as a union of interconnected micro grids which may be disconnected from the smart grid and operate autonomously in island mode (Bower et. al., 2014). Analogously to a smart grid a micro grid also consists of the same structural components as a smart grid. A smart grid subdivided into micro grids has the potential to restrict cascading effects and hence to be less vulnerable against disruptions. Cascading effects due to dysfunctionalities of certain components or propagation of malware throughout a smart grid might be prevented by disconnecting the affected micro grids from an overall smart grid. Although having isolated dysfunctional micro grids from the smart grid of a city, CI interdependencies may cause issues in other parts and reduce the resilience of the city as a whole.

Today, there are first practical concepts and schematic framework definitions available how to deploy micro grids to serve electricity to local CI providers e.g. (Jung et al., 2016; New York State Energy Research and Development Authority et al., 2014).

Referring to the previous section on power outage response activities the EMS or DMS of a smart or a micro grid should focus on the maintenance of CI services. The topology of a smart grid in the sense of the preceding paragraphs has a massive influence on the possibilities of how an EMS makes decisions for example if it seeks for certain equilibrium states. Therefore an EMS should also take into account the implemented and available coping capacities of the CI services and the disaster management authorities. The objectives in this escalation stage should be to secure the maximal possible maintenance of CI services.

This motivates the following question Figure 2:

A) What are optimal micro grid configurations for a city in the sense of maximum urban resilience?

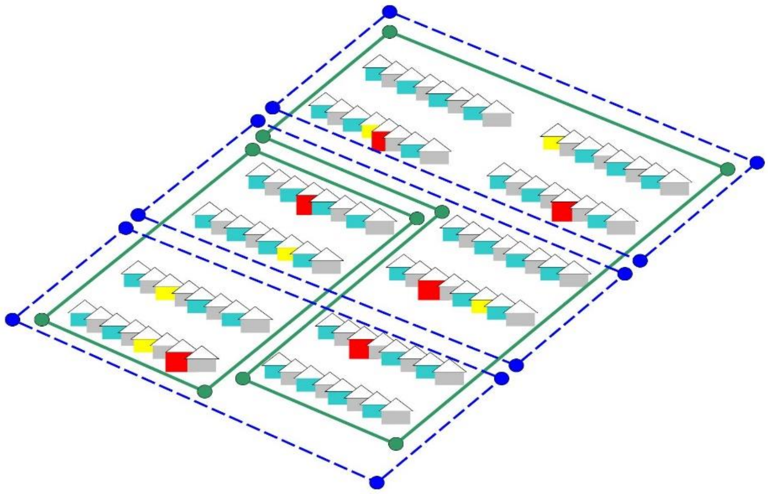

Figure 2. A city contains of multiple buildings. Red and yellow colored buildings indicate different CI types in some segments of a city, where varying sizes imply varying levels of importance of the CI type. The union of green framed and the union of blue framed areas subdividing this urban segment represent two different versions of micro grid installations resp.

Another aspect of grid design is the topology of LANs - number and configuration of components like concentrators, overlaying network structures to provide redundancies - may have an effect on vulnerability.

This further topological degree of freedom implies the following question Figure 3:

B) What are optimal configurations of components e.g. concentrators or intelligent knots in general within a smart/micro grid in the sense of maximum urban resilience?

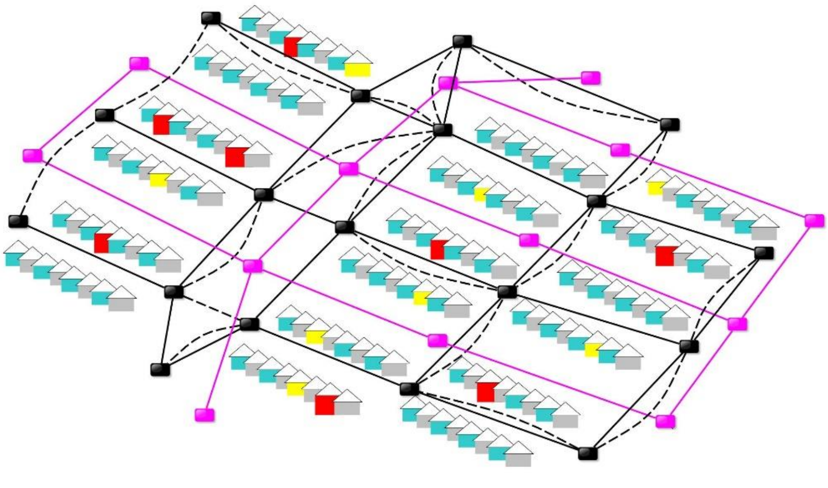

Figure 3. Red and yellow colored buildings indicate different CI types in some segments of a city, where varying sizes imply varying levels of importance of the CI type. Black and pink knots representing intelligent knots belong to different networks. There are three different networks: Two black networks - continuous and dotted edges -, the pink network.

AGENT BASED SIMULATION OF CRITICAL INFRASTRUCTURES

Models such as Aspen by Sandia national lab, SMART by Argonne national lab, and CIMS have demonstrated that agent based simulation is an appropriate method for assessing CI interdependencies and CI disruption impacts - for a review see (Ouyang, 2014; Pederson et al., 2006). The agent based approach seems to be very promising for addressing the questions A) and B) which we posed in the previous section.

The key idea of the agent based approach under consideration is to represent urban CI entities like hospitals, pharmacies or components of CIs e.g. smart grid components by appropriate software agents, where an agent is located in some environment and is able to behave in an autonomous manner according to a specific set of predefined rules. Based on practical experiences, the distribution of responsibilities and the power of decision making, and the legal perspective, this focus is highly beneficial for end-users in the light of specific spatial-temporal circumstances due to a disruption taking into account concrete characteristics of CI entities in the considered urban region e.g. CI type, size, location, implemented coping capacities, interdependencies. This approach enables to identify appropriate counter measures that are specifically tailored to the circumstances of the considered urban area.

Agent modelling of a city's local CI entities/components considered as service providers, e.g. water supply networks, hospitals or smart/micro grid components requires a fundamental grasp on

- internal processes in order to gain a notion of how the state of an agent or a concrete CI facility like a hospital or a pharmacy depends on external factors,
- the way how they are physically embedded into the environment and virtually attached to cyber-, communication- and information networks, and
- the types of services that are offered.

Dysfunctionalities of such entities caused by natural disasters or malicious attacks may have a massive impact on vital services and trigger some sort of crisis management. Depending on the type, massiveness, duration of disruptions and the types of involved CIs or CI components the following possible crisis management patterns are thinkable:

- CI entities belonging to the same type may organize themselves locally in groups pursuing an optimal provision of services following a prioritized list of tasks which should be fulfilled. This procedure seems to be an effective way of targeted communication with external groups of the same entity type or a crisis management group as well as realization of concrete measures.
- Within these groups negotiations may lead to solutions pursuing protection target levels or equilibrium states such as the minimum level of supply.
- A crisis management group collecting information from various CI owners and stake holders can assess the city's state and in case of depleted coping capacities of CIs decide to intervene by applying certain counter measures.
- If we think about enhanced installations of smart grids, certain counter measures may be triggered automatically by *real-world* agents without involving human decision making processes by self-healing capacities see for example (Deconinck et al., 2008, 2010; Rigole et al., 2008), where these *real-world* agents are included into our model as agents representing CI components.

The agent's behavior based on accessible environmental or internal status data e.g. degree of availability of important resources like electricity or power etc. is endowed with crisis management capabilities in the above sense. The way crisis management or negotiations is performed can be parametrized which itself may serve as decision support for response during a crisis. CIs from all sectors are successively included into the model according to a prioritized list. The first maturity level of the model focuses on the implementation of electricity supply, water supply, and entities of the health sector such as hospitals, pharmacies, GPs, etc.

A generic tool for specifying disruption scenarios, interpreted as the temporarily lasting failure of services provided by CIs or CI components represented as agents, is a crucial part of the simulation framework.

Having setup a simulation framework which complies with the paradigm of agent based modelling in the aforementioned sense plausible disruption scenarios e.g. a local six hours lasting power outage may be simulated and resilience of certain CIs or the city as a whole may be assessed (for more insights of our previous work also see Münzberg et al., 2017A; Raskob et al., 2015A, 2015B).

An application that allows the assessment of resilience of cities serves as a suitable tool for decision support for crisis managers as well as urban planners if it offers the opportunity to vary model related parameters like CIs' response activities, negotiation patterns, crisis management, determinations of protection targets or the design of CIs.

Certain entity types - water supply, hospitals, pharmacies, and dialysis clinics - of the city of Karlsruhe, Germany, were preliminarily modelled as agents using the REPAST agent framework in eclipse Figure 4

Figure 4. An agent based realization of some critical infrastructures of the city of Karlsruhe. The different icons indicate water supply, hospitals, pharmacies, and dialysis clinics. The green and blue bars indicate the state of the power respectively water supply of the according structure for the considered point in time of the simulation.

Much work has to be done concerning building adequate agent models and their validation. We have already realized expert workshops (see Münzberg et al. 2017B), but we are also accompanied by CI providers and practitioners to ensure validity of our models and end-user orientation.

SMART GRID TOPOLOGY CONSIDERED AS MODEL PARAMETER - RESILIENCE ASSESSMENT AND DECISION SUPPORT

In the section on smart grids we shed some light on possible design options for smart grids in an urban context:

- subdividing a smart grid into interconnected micro grids which may be isolated from the overall network
- configurations of intelligent knots in local networks.

These topological degrees of freedom can be considered as model parameters which also may be varied i.e. changing parameters means changing the smart grid topology.

Power outages in cities which utilizes complex smart grid technologies with a high degree of connectivity of CIs or CI components of different types may expose new or rather unexpected interdependencies of CIs.

A simulation framework based on agent based modelling as depicted in the previous section may enable decision makers, urban planners or power providers to find optimal solutions for enrolling or enhancing smart grid technology in the sense of robustness.

In the light of the two resilience related questions A) and B) in the section on smart grids many smart grid instances may be tested against a vast number of disruption scenarios, e.g. cyberattacks on smart grid components.

Referring to question A) in the section on smart grid structures the following simulation type is proposed: CIs of varying importance and relevance are distributed over an urban area. Different arrangements of micro grids can be taken into consideration where CIs of one type can be located in different micro grids depending on their importance, e.g. one micro grid shouldn't accommodate too many of the biggest and most significant hospitals in the city; it seems to be more sensible to have them in different micro grids. The EMS might enforce the disconnection of certain micro grids from the overall network in case of failure of crucial components in order to protect CIs and reach certain protection target levels.

Referring to question B) in the section on smart grid structures the following simulation type is proposed: Certain redundancies may be tested in the sense of overlaying network structures. Certain CIs should not only depend on just one connected local network - i.e. failures in parts of one local network wouldn't imply an interruption of the power provision of the CIs since other undisrupted parts of the micro grid to which the CIs are also connected are still able to deliver power.

With the help of systematic studies of urban resilience related quantities by combining the aforementioned simulation types smart grid topologies which are adverse may be identified but also those which are optimal in the sense of robustness or urban resilience Figure 5 - comparing different topologies against certain disruption scenarios resilience related quantities which apply the maximum achieved safety condition see Figure 1 may be taken into account.

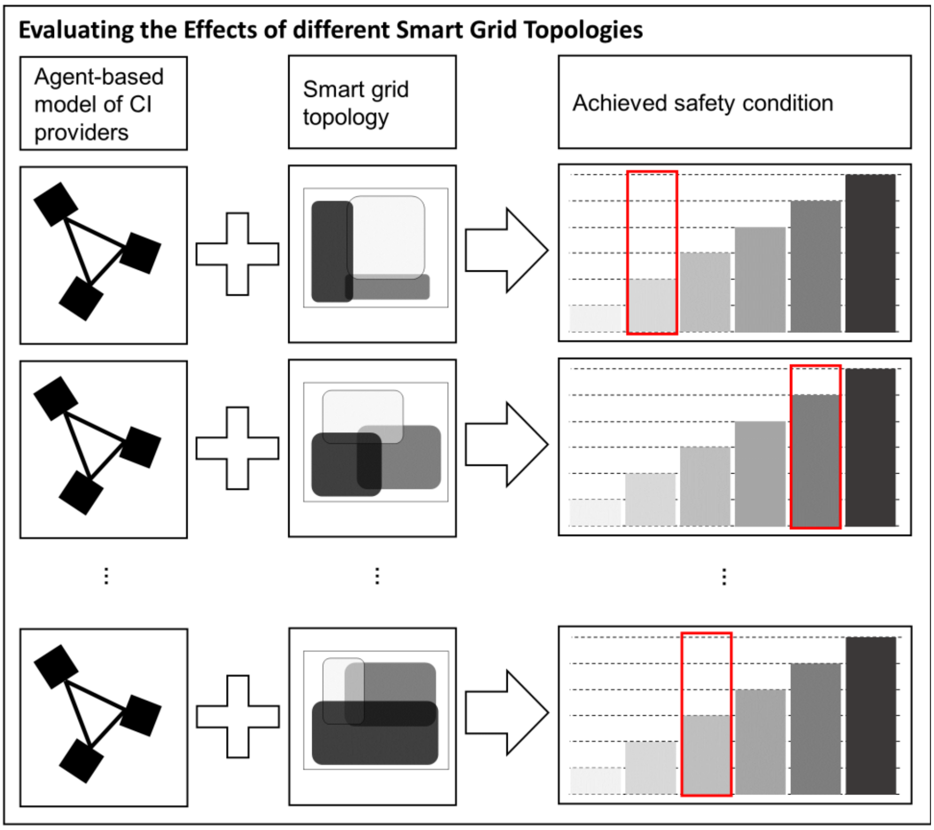

Figure 5. Resilience assessment of smart grid topologies against disruption scenarios via agent based simulations.

Best robustness results can further be evaluated against cost efficiency aspects to find optimal smart grid solutions.

CONCLUSION

Modern smart grid technologies are based on a high degree of connectivity and automation in order to integrate a vast number of distributed energy resources in a reliable way. In the light of CIP such complex networks bear the potential of increased vulnerability if the EMS and DMS are not adequately prepared. This work emphasizes the massive impact of smart grid topologies on urban resilience referring to the adequate provision of CI services.

Our agent based simulation approach, where CIs and CI components are modelled as agents embedded into an environment and virtually attached to cyber-, communication- or information networks, also includes the ability to define various disruption scenarios.

Although agent based modelling relies on a great quantity of input data it gives many opportunities to evaluate and develop resilience improvement strategies (Ouyang, 2014), and among others a major property is scalability i.e. new CIs or CI components may be successively modelled, and included into the environment or any network.

As described in this work our ongoing research aims to interpret the topological degrees of freedom for designing a smart grid as model parameters which may be changed to realize different smart grid topologies which themselves are studied against various disruption scenarios.

By assessing different CI dependent smart grid topologies and enhanced EMSs pursuing certain protection target levels we may identify those which are adverse but also those which are optimal in the sense of robustness or urban resilience.

It would be interesting to compare our analytical findings and modelling approach with the results of system dynamic approaches like those of (Canzani, 2016; Laugé et al., 2015) and other interaction models like those of (Turoff et al., 2014) resp.

A main objective of our ongoing research is to establish a software tool based on agent based modelling which supports decision making during a crisis as well as facilitates city planners or CI owners to design or redesign future or existing CIs e.g. smart grids.

ACKNOWLEDGMENTS

The presented work is part of the Helmholtz Association's (HGF) portfolio project "Security Research" and of the critical infrastructure protection activities of the Center for Disaster Management and Risk Reduction Technology (CEDIM). CEDIM is an interdisciplinary research centre of the Karlsruhe Institute of Technology (KIT), Germany, which is also member of the International Centre of Excellence for Critical Infrastructures and Strategic Planning (IRDR ICoE-CISP). The HGF's and CEDIM's financial support of the work is gratefully acknowledged.

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New Decision-Support Framework for Strengthening Disaster Resilience in Cross-Border Areas

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ABSTRACT

The improvement of disaster resilience in cross-border areas causes special challenges. Involved countries use different structures in their civil protection systems and have to work together facing more difficult conditions than in local incidents. Furthermore, in the past involved countries mainly worked individually and focused on the concerned areas in their territories regardless transnational activities. The project INCA will develop a resilience framework to support decision-makers. The framework will focus on information management, the implementation of volunteers and the needs of citizens who are receiving medical care. Therefore, a case study region on the German-French border was defined and a scenario-based approach will be used to investigate resilience opportunities through disaster collaboration. The tested scenario is a transnational long-lasting power-outage in the German-French region.

Keywords

Cross-border events, cross-border resilience, information management, interorganizational cooperation, disaster resilience

INTRODUCTION AND MOTIVATION

Big incidents are often multinational and cross-border events. (Pappert et al. 2015) E.g. the big flooding in central Europe in 2013 involved the countries Germany, Poland, Austria, Switzerland, Slovakia, Czechia and Hungary. Only in Germany, it caused a damage of about 11.6 billion EUR. (Thieken, 2015) These kind of incidents require cross-border close collaboration between the involved countries to grant effective disaster response actions.

To improve cross-border collaboration a few research projects and research groups have been dealing with this topic such as the EU project DISASTER (Data Interoperability Solution At Stakeholders Emergencies Reaction), which developed a methodical basis for connecting IT-based emergency management systems based on end-user requirements. The generated ontology called EMERGEL (EMERGency ELements) includes linguistic, semantic, legal, and structural issues that are important to share information between all involved countries. The project DISASTER focused on highly applicable interface which allows countries to use their own familiar system instead of untrained new ones. The country specific systems are connected and translated via the EMERGEL platform. (Pappert *et al.*, 2015; Cepeda, 2015)

In this paper a new project is introduced called INCA (A Decision Support Framework for Improving Cross-border Area Resilience to Disasters), which starts in the beginning of the year 2017 and focus on understanding and enhancing cross-border resilience. The focus is set on the resilience of medical dependent citizens and the management of volunteers in a cross-border area. Therefore, the scenario of a cross-border blackout will be defined. Within this scenario, particular areas both on the French and on the German side will be examined. The chair for Public Safety and Emergency Management at the University of Wuppertal will mainly focus on these topics: management of (spontaneous) volunteers, the resilience of medical dependent citizens and the interagency cross-border collaboration of the response agencies. (Rigaud & Schultmann, 2016)

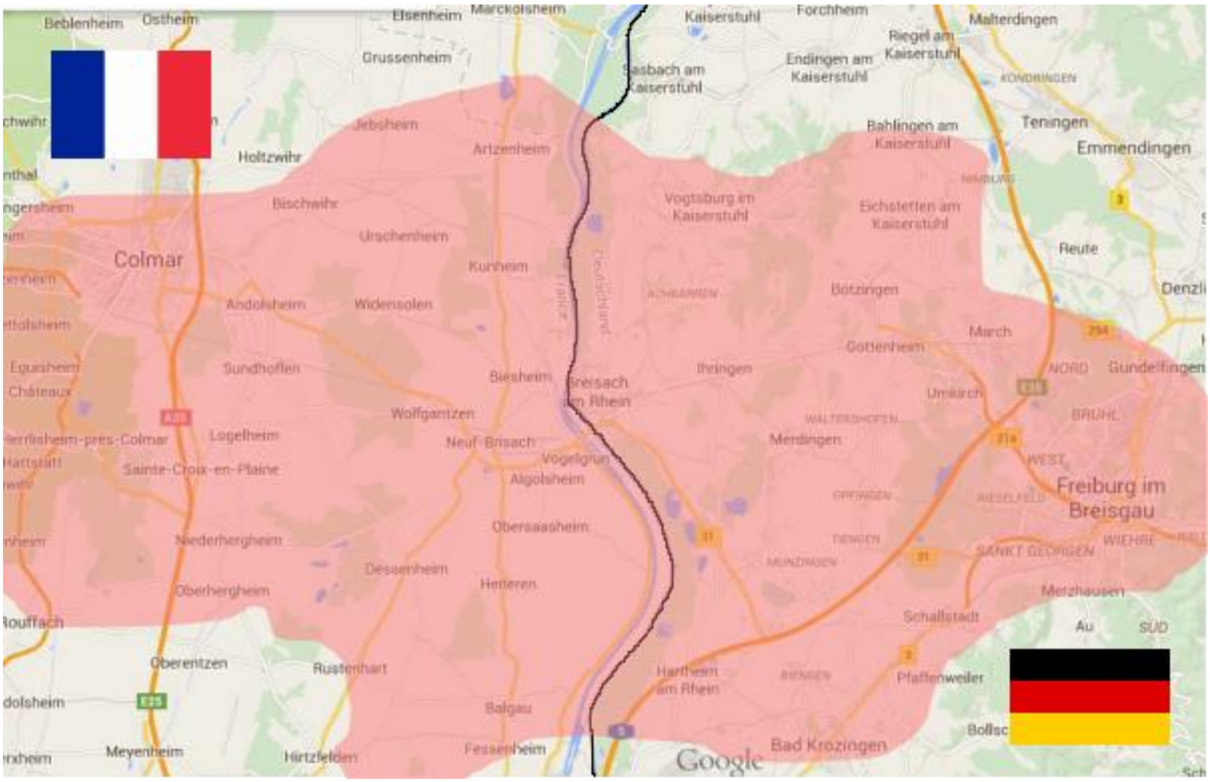

Figure 1: Case study region with possible power-outage (Source: Google Maps modified by authors)

DIFFERENT STRUCTURES IN CIVIL PROTECTION SYSTEMS

One of the main reasons for ineffective cooperation during cross-border events is the differences in structure and culture within the civil protection systems of the involved countries. Not only language barriers but also differences in organizational structures can cause lacks of information for at least one player. Furthermore, the differences in the system can even lead to situations, where parts of the equipment of the involved forces have not the needed admission for other countries and therefore cannot be used as usual. (Ministry of Home and Municipal Affairs North Rhine-Westphalia, 2014, p. 69, 2014)To fix this problem, there are already several approaches: The European Union (EU) has introduced the European Civil Protection Mechanism (ECPM) in 2001. Within this program, the members of the EU (and some other neighbour countries) support the coordination centre with a pool of resources and information. These resources can be used for incidents in other countries within and out of the EU. Since today, this service is well established and has not only been used in Europe, but all over the world for example during the earthquake in Haiti (2010), the triple-disaster in Japan (2011), the floods in Serbia and Bosnia and Herzegovina (2014), the conflict in Ukraine (2014). (European Commission, 2016) Furthermore, the ECPM focuses on the properties of compiling an inventory of assistance and intervention teams, establishing a training programme for members, setting up assessment and coordination teams, establishing a Monitoring and Information Centre (MIC) later called Emergency Response Coordination Centre (ERCC) and a common communication and information system. The established Common Emergency Communication and Information System (CECIS) deals with detection and early warning systems, as well as facilitating access to equipment and transport by providing information on the resources available from Member States and identifying resources available from other sources. (European Commission 2016)

Although, the *European Civil Protection Mechanism* is a system with international partners and members, and forces from different countries, it does not really address cross-border events and does not focus on improving the close cooperation between two players with different civil protection systems during a common event. Its objective is to support overcharged countries by providing useable resources, which are needed at that moment. Furthermore, the participation *European Civil Protection Mechanism* is voluntary. (European Commission, 2016; Ministry of Home and Municipal Affairs North Rhine-Westphalia, 2014, pp. 67–69)

Other approaches address the problems of cross-border events directly. Good examples for these approaches are common or daily events such as medical emergencies within the region of Germany, Belgium and the Netherlands, which are very well examined. The cooperation is founded on contracts and common, elaborated concepts. These concepts are also addressing the information flow and information exchange between the involved stakeholders of the countries. This leads to better services, e.g. it is easily possible for a German ambulance to deliver the patient to a hospital in the Netherlands. (Ramakers *et al.*, 2007)

German Structure of Civil Protection

The Federal Republic of Germany has a federal political system and is split in 16 states (so called Bundeslaender). The responsibility of civil protection is delegated to the federal states. After the Second World War, the allies allowed to found the technical relief organisation as first civil protection institution to help in case of air raids. Later, the *Federal Ministry of Interior* took responsibility for civil protection by allowed delegation. During the development of the *Federal Ministry of the Defence*, the competences of civil protection were strictly divided into the two cases of war time (civil defence) and peace (civil protection). Due to the fact that war affairs are on federal level, each federal state has been responsible for the civil protection in times of peace. The federal states delegate fire protection and emergency medical services to the different counties under the superstition of different district administrations. In 2004 after the two events - the great flooding in Germany and 9/11 - , the Federal Ministry of the Interior established the *Federal Office of Civil Protection and Disaster Assistance* in order to provide a coordination centre for cross-state incidents as well as common educational training of disaster management forces. Today, civil protection is still part of the legal states regulated in 16 different laws but mainly adjusted to same principles. (German Federal Office for Civil Protection and Disaster Assistance, 2010)

French Structure of Civil Protection

Since the French Republic is a unitary republic, the responsibility for national civil protection is allocated at the *French Ministry of Interior* and for regional civil protection at the departmental fire and rescue services. The prime minister of France is responsible for the civil protection in the whole country. Unlike in Germany, in France the systems of civil protection and civil defence are not strictly separated. Rather, both systems share same structures and the fire brigades in Paris and Marseille are even military organizations. Although, there are different ministerial responsibilities for incident management depending on the dimension of the incident (see Figure 2), the *French Ministry of Interior* specifies the structure of the local solutions for the civil protection systems. (Coste *et al.*, 2013; European Commission, 2015)

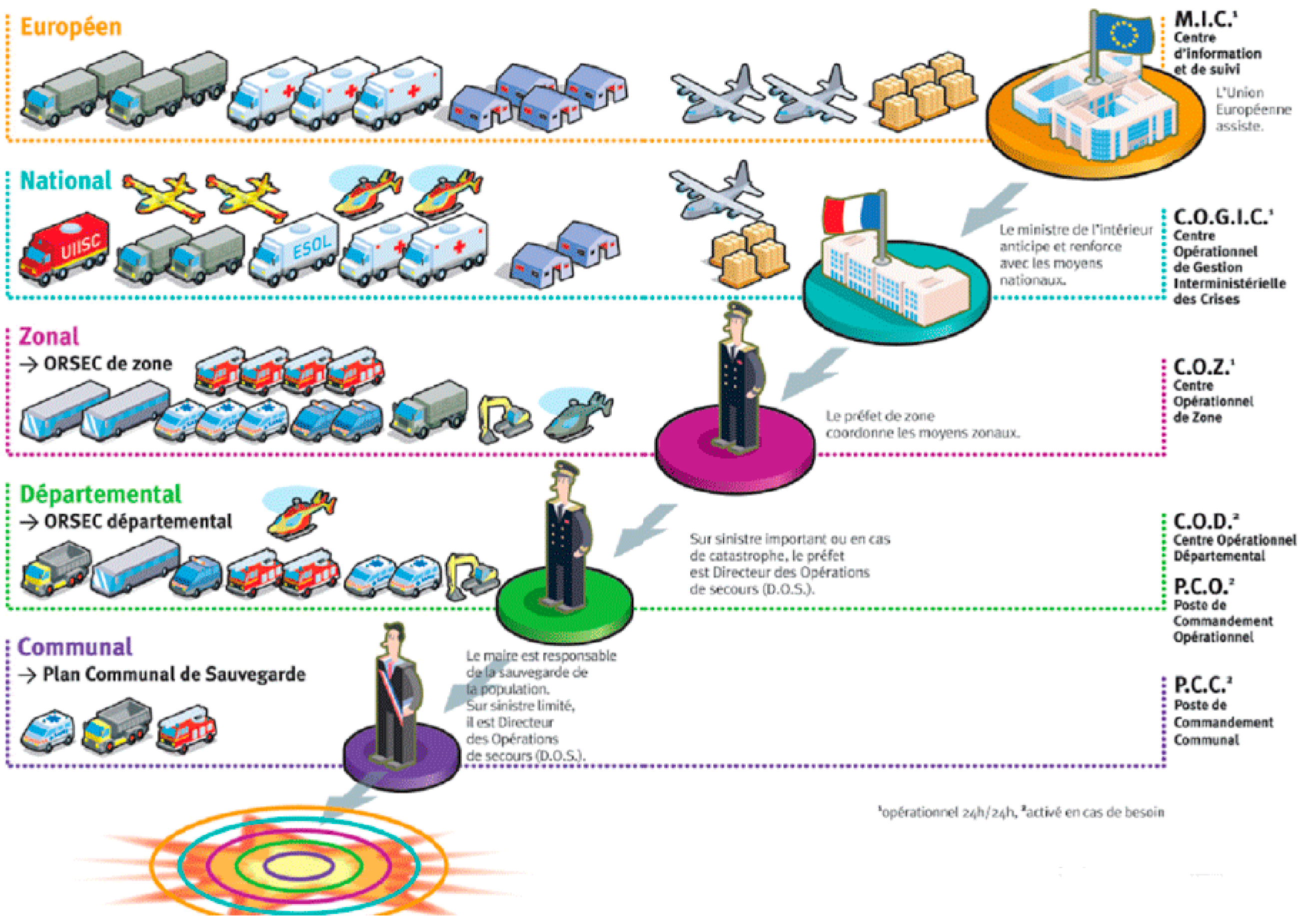

Figure 2: Structure of the French Civil Protection System (Source: Institute for Major Incidents, 2012)

Both nations have a different structure to deal with events concerning civil protection. Table 1 shows the comparison briefly. This has to be considered in the development of a methodology to develop a new decision support framework for transnational disaster management collaboration.

Table 1: Comparison between German and French system

	German system	**French system**
general organization	federal system (every federal state is responsible for its territory and can make its own laws and plans, the government of the Federal Republic of Germany can never take over control)	centralized system (different responsibilities depending on the dimensions of the scenario, the prime minister of France is responsible for the whole system)
separation in the responsibilities between civil protection and civil defence	yes, federal states are responsible for civil scenarios, the government on the Federal Republic of Germany is responsible for non-civil scenarios	no, there is even a close link between the system for civil protection and civil defence

METHODOLOGY

Within the project INCA, a scenario-based approach will be used. Based on the power-outage scenario and a study case area (Figure 1), the authors will examine different aspects of cross-border events. The main goals are:

- development of recommendations for the implementation of volunteers during cross-border events,
- development of recommendations for improving the international and inter-organizational information management,
- support the development of a decision-support-system,
- analyse the needs of medical dependent people.

Based on the lessons learned in one scenario, in the final phase of the project the results will be transferred to general, scenario-independent recommendations which shall be provided to end-users.

INCA Scenario

In order to keep limit to the research effort to a manageable size, the consortium of project INCA is using a scenario-based approach with focus on a long-lasting power-outage. This scenario is particularly challenging due to its complexity, interdependencies to other critical infrastructures, and great challenges for preparedness by public authorities. For example, the German Federal Office for Civil Protection and Disaster Assistance (BBK) occasionally admitted that long lasting power-outages represent a significant threat as they are by now systematically underestimated. Furthermore, this scenario implies a high level of difficulty as such a threat directly affects emergency services themselves: In contrast to an earthquake, where a given hospital capacity meets an exceptionally high demand, a long-lasting power-outages constrain the needed capacity of health services seriously. Additionally power-outages are actual and transnational problems. Especially fluctuations in the electricity grid (caused by the raise of renewable energy and the use of smart grid technologies) lead to a higher risk. (Leavey, 2012; Lund *et al.*, 2012)

The detailed scenario description will be defined in the initial phase of the project and will include information related to the geographic area, critical infrastructure (CI) interdependencies, health sector details as well as preparation levels of the public. In addition, the ability of resilience capacities of the affected society such as volunteers' involvement and their implementation in civil protection structures will be addressed. As mentioned above, during the final phase of the project a broader set of scenarios (e.g additional natural disasters) will be developed in order to analyse the transferability of the developed decision support framework to other used-cases. (Rigaud & Schultmann, 2016)

Information management in cross-border events

A great challenge of effective disaster response actions during cross-border events is the use of a very well developed information-management-system. Due to the fact that Germany and France are using different civil-protection systems, the information flows between the involved authorities in both countries are not as efficient as on local level.

To improve the international and interorganizational information management, process-modelling and flowchart methodology will be used to identify important connections between the involved forces in both countries. This action has already been successfully used in the past as discussed by Fahland, Woith and Lindemann and within the project VERVE. (Lotter *et al.*, 2015; Fahland & Woith, 2008; Lindemann *et al.*, 2010) The focus within INCA will be set on identifying the connections between the involved forces of Germany and France. To gain the required data, stakeholders and experts will be involved in the process. The focus will be set on interviews with the decision-makers.

Volunteers in cross-border events

Integrating the interaction with volunteers in a dynamic setting of disaster management is also an important step. "*Recent examples like the 2013 Elbe flood and spring storms in Germany or the 2013 typhoon Haiyan in the Philippines show that volunteers play a vital role during disaster response.*" (Rigaud & Schultmann, 2016, p. 6) Since today, these volunteers often work independently from official disaster response authorities/organizations. This might cause problems in coordination and collaboration (Fernandez, 2007) and sometimes additional risks such as putting themselves in jeopardy.

Within the project INCA, the focus will be set on gaining information about the motivational aspects, cultural differences, capabilities, and willingness to integrate in formal response networks of volunteers. A first attempt of evaluating the motivation of volunteers has been executed in an empirical study by Fathi et al. in 2015. They conducted a survey questioning volunteers, which were involved in disaster events over the past years. Based on their research INCA will gain more data about the phenomena of the inclusion of spontaneous volunteers through document analysis, focus groups and structured interviews. (Fathi *et al.*, 2015)

The focus in INCA will not be set on the inclusion of all spontaneous volunteers together and in both countries. Furthermore the project will examine how to implement volunteers in the most effective way, e.g. split the volunteers into small groups, led by professional forces, merge all volunteers and deploy them together or support them within the work, they are already doing.

Citizens receiving medical care

Apart from the improvement of disaster-information-management and the integration of volunteers during cross-border events, the project INCA will also analyse the impact of the power-outage on citizens receiving medical treatment. Especially this scenario has enormous consequences for this group of citizens that cannot be neglected. Not only hospitals, retirement or nursing homes must be considered as well, but also medically treated citizens who are living in their own homes. Today, some organizations provide shared flats for inhabitants that are depending on respirators. These flats are not registered and an increasing challenge. Unlike hospitals or nursing homes, “ordinary” flats do not have an emergency power supply, which provides electricity for the respirators during power-outages. Nevertheless, not only electricity is needed for high-tech medical devices, fresh water supply, heating and food supply have be considered as well. In the future the demographic change will cause a rising number of senior citizens in the population and therefore an assumed increase of citizens dependent on medical treatment as well. (Rothgang *et al.*, 2015; Petermann *et al.*, 2011)

The INCA decision support framework

The project INCA addresses the above challenges by developing a methodical resilience framework. Figure 3 shows the structure of the research framework and its methods briefly.

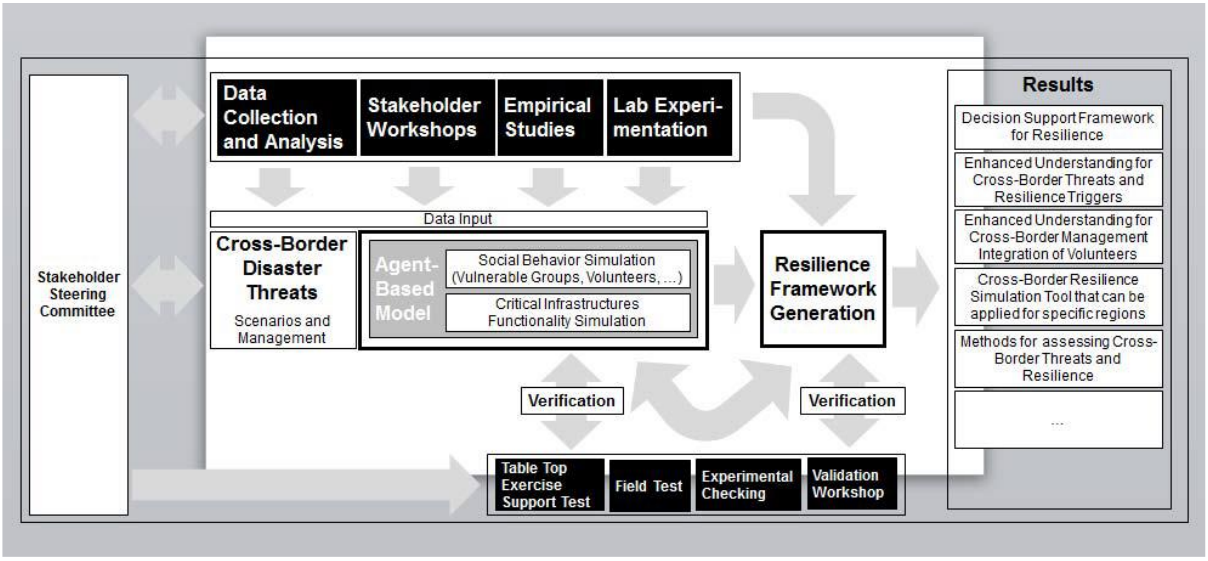

Figure 3: Research framework of the project INCA (Source: Rigaud & Schultmann, 2016, p. 9)

Based on the scenario, data collection and analysis of past events, workshops with stakeholder groups, empirical studies and lab experimentation are used to gain data input for the agent-based model. This model will be used to design and develop the structure of a decision-support system. Accompanying measures are empirical studies of other big parts of the project, medical dependant citizens and voluntary management during cross-border events. To verify the developed features of the decision support system, it will be reviewed iteratively. Therefore, table-top exercises and field tests are planned as well as validation workshops with stakeholders. A triangulation of the results is planned to derive valid results for the transfer into an integrated resilience framework. This framework will provide a decision-support system and will help to enhance the understanding for cross-border threats as well as the integration of volunteers. An own agent-based simulation can be applied for specific regions and scenarios. (Rigaud & Schultmann, 2016)

During the empirical studies on the integration of helping hands of volunteers, different possibilities shall be evaluated for managing these quite new phenomena in crisis management (Rigaud & Schultmann, 2016). Because of the cross-border aspect, there will also be a focus on cultural aspects and differences between volunteers in Germany and France. At the end of the project, specific recommendations for the implantation of volunteers in different scenarios will be developed. Furthermore, examples of successful common disaster response work among/between authorities and volunteers are used to illustrate the benefit of societal strength in times of disaster. A guideline with recommendations for the integration process will be published for disaster response organisations.

Via identifying the critical points in the information management between Germany and France it shall be outlined where an improvement might be necessary. These improvements can range from tools for translation up to the implementation of already developed IT-support-systems (e.g. project DISASTER, see Cepeda, 2015) or recommendations for changing communication paths.

The description of the medical needs of citizens with medical care/treatment will be implemented in the decision-support-system. This approach will give the decision-makers the possibility to set priorities more easily and receive an overview of the consequences of different alternatives. The needs of the medical dependent citizens will first be outlined for the blackout scenario. But afterwards there will be support for other scenarios as well. Therefore, the needs of citizens will be clustered according the categories electricity, water supply, food supply, etc.

CONCLUSION & PERSPECTIVES

The development of a resilience framework will help the decision-makers before and during cross-border incidents to improve the resilience of these areas. Responsible people can use the guidelines to focus on different scenarios and figure out, which measures are most suitable for their specific problems and areas. Furthermore, the focus on cross-border incidents and the possible impact will hopefully raise the awareness for the difficulties of complex events with different involved countries and stakeholders, especially end-users from the above-defined region (e.g. fire-fighters, paramedics).

It is not the goal of the project to effect changes on the policy level, such as changing laws or the implemented disaster-management structures, but rather improve the communication between the involved end-users and provide tools for faster and more reliable decisions. The decision support system should first of all assist the users to develop their decisions and afterwards share the results with the other involved partners (especially those from other countries), to raise efficiency.

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Resilience engineering and management

Embedding Unaffiliated Volunteers in Crisis Management Systems: Deploying and Supporting the Concept of Intermediary Organizations

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ABSTRACT

Citizens engaging in crisis management spontaneously and without affiliation to an (honorary) aid organization are a social phenomenon on the rise. Even though public engagement is desirable, it receives mixed reactions by crisis management experts. They claim that "the crowd" has to be managed to ensure a successful crisis response and recovery, leading to high coordination efforts which cannot be achieved by the authorities. To understand the obstacles in cooperation and to overcome them better, this study examines existing patterns of cooperation. The study employed in-depth interviews (n=13) in two use cases (flooding, n=4; migrant crisis, n=9) with public authorities, aid organizations and engaged citizens. Results indicate that collaboration works successfully when an intermediary organization bridges the coordination gap between authorities and the public. In addition to the concept of intermediary organizations, two ICT approaches supporting collaboration in crisis events are described: Public Displays and the so-called 'Security Arena'.

Keywords

Crisis, Disaster Control, Civil Society, Embedding Unaffiliated and Spontaneous Volunteers, Intermediary Organizations

INTRODUCTION

In case of emergency or disaster, in most nations three different groups of people come to the fore: (1) the professional public authorities with security responsibilities, emergency services and private aid organizations with a high level of responsibility for most of the tasks during the response and recovery work, (2) the honorary emergency services and aid organizations that are quite similar to and often perceived as equal to paid 'professionals', and (3) engaged citizens who offer their help in various ways during events of crisis. Even though civic engagement is a noble gesture, engaged citizens are quite often not perceived as equal. In many cases, public authorities and aid organizations share an attitude towards them as "the crowd to be managed".

At the same time and as a result of an aging society, demanding jobs, the challenge of work-life-balance, and more frequent relocations in the course of life, the interest in a long-term bond to an honorary office in disaster control has receded in many regions (Angermann & Sittermann, 2010; Cronenberg, 2015; Gensicke & Geiss, 2010). Honorary aid organizations suffer from a considerable decline in new memberships, and in Germany, the suspension of the mandatory military and civilian service has further tightened the situation (INKA-Forschungsverbund, 2015). Thus, unaffiliated and spontaneous civic engagement plays an increasingly important role in disaster control and crisis management. In line with this, several events of natural disaster, like the European flood in 2013, and the European migrant crisis in 2015 have sparked tremendously spontaneous civic engagement. Unaffiliated volunteers who were not part of the honorary aid organizations or public authorities in charge, offered their resources and joined forces to fill sandbags or assemble camp beds for refugees. Quite often, those volunteers communicated with each other and coordinated their activities via social media services like Facebook and Twitter or via messaging services like WhatsApp, encouraging family and friends to engage. Even though public authorities and aid organizations have been confronted with spontaneous and unaffiliated civic engagement for quite some time, the scale, rapidity and ways of organization is a recent phenomenon.

Paradoxically, this desirable engagement received mixed reactions by disaster control and crisis management experts. Although attitudes have shifted in recent years and the boundaries of their activities are blurring, previous research (INKA-Forschungsverbund, 2015) has shown that the group of engaged citizens is still only slightly into crisis management processes. Even though experts assess embedding spontaneous and unaffiliated volunteers into crisis management processes as strategically relevant to their organizations, they claim that high management and coordination efforts, a lack of training as well as legal and cultural issues interfere with integration. In addition, detailing an operational plan without having evidence how many volunteers show up in a specific crisis situation challenges the integration and systematic involvement. Thus, the resources of the civil society quite often remain untapped and the emergence of community strength and resilience (Berkes & Ross, 2013) is constrained.

Therefore in our paper, we intend to introduce an organizational concept as well as ICT tools which are able to support an effective and efficient integration of the public into crisis management processes. We first present the theoretical background and related work with regard to emergent citizen groups in events of disaster (Section 2). Based on an extensive empirical study (Section 3), we then derive and describe the organizational concept of intermediary organizations which assume to occupy the position of a mediator between public authorities and emergent citizen groups (Section 4). Subsequently, we present ICT approaches supporting the establishment and deployment of intermediary organizations in events of crisis (Section 5), and point out how these concepts can support the development of collaborative resilience as an overall goal (Section 6).

THEORETICAL BACKGROUND

As summarized by Dunn (2015), early work of Prince (1920) or Deacon (1918) has already examined collective behaviors during disasters. They have revealed that disasters are events in which extensive mixed collective behavior can be observed which occurs as new and different to everyday behavior (Perry & Quarantelli, 2005). Deacon (1918) observed that "immediately and spontaneously neighbors and fellow-townsmen spring to the work of rescue and first aid". Dynes (1970) produced a fourfold typology of organized behavior in disasters (Figure 1). This typology classifies organizational behavior based on the two dimensions 'structure' as well as 'tasks' and encompasses organized behavior as established (regular tasks, old structures), expanding (regular tasks, new structures), extending (non-regular tasks, old structures), and emergent (non-regular tasks, new structures).

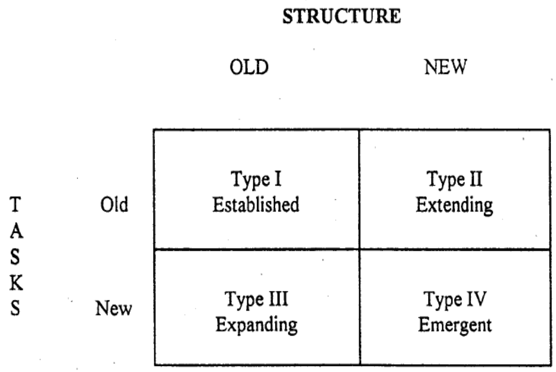

Figure 1: Organizations in Disasters (Dynes, 1970)

As Quarantelli (1995) argued, early studies mainly focused on the first three types of organizational behavior during disasters and only few studies have researched emergent behavior in a systematic way. These few studies, however, focused mainly on "later stage conditions associated with crystallization and institutionalization, rather than on the characteristics of emergent groups, and the early stages of emergence" (Quarantelli, 1984). Stallings & Quarantelli (1985) describe the early and often spontaneous forms of citizen-based crisis management, with new structures as well as new tasks, as „emergent citizen groups" which are characterized as "emergent groups (e.g. unaffiliated volunteers) [which] undertake activities that were previously foreign to them and develop a social structure that lacks formalization, tradition and endurance" (Stallings & Quarantelli, 1985). These emergent groups are therefore characterized by a new (social) structure with new goals and tasks in their response to an emergent situation. Only if both requirements (a new structural arrangement and the undertaking of tasks which were new to the group) are fulfilled, the arising collective citizens' initiatives are properly referred to as emergent groups (Stallings & Quarantelli, 1985). Emergent groups range "from ephemeral teams of neighbors attempting search and rescue, to community residents organizing themselves to force removal of potentially hazardous waste sites or nuclear plants, to disaster victims getting together to pressure officials to take preparedness and mitigation measures for probable reoccurrences of the floods and landslides they have just experienced" (Stallings & Quarantelli, 1985).

It should be noted that civic engagement also takes place within various organizations which are already established. Thus, emergent citizen groups are "only part of the full range of emergent phenomena to be expected before, during, and after disaster threats and impacts" (Stallings & Quarantelli, 1985) and often private citizens initiate new groups based on their already established work roles. On the other hand, organizations often arise from emergent groups. Stallings & Quarantelli (1985) outlined that one necessary condition for the emergence of citizen groups *during* a disaster is a perceived need or demand which requires immediate action. Emergent phenomena occur when those needs and demands are not met by existing organizations (Heide, 1989). And especially during disaster, the public authorities with security responsibilities can "experience such a rapid and unexpected increase in demands that they lack capabilities to deal with them" (Parr, 1970). Here, inter-organizational coordination and the confrontation with disaster produces demands far beyond the organizations' routine capabilities, and as a results poses several problems (Stallings & Quarantelli, 1985; Ley *et al.*, 2012).

Emergent citizen groups are not inherently in opposition to the public authorities with security responsibilities and most of the groups start out with "the notion that public officials will be on their side once their attention is called to the issue" (Stallings & Quarantelli, 1985). Nevertheless, when considering the perception of emergent citizen groups by crisis management experts, it is obvious that emergency services "often do not take them into account in community emergency management planning and misunderstand both the reasons behind their emergence and the roles they play in disaster-related community problems" (Stallings & Quarantelli, 1985). Although public authorities with security responsibilities and aid organizations have recognized the relevance and importance of citizen-initiated physical and digital activities, emergent citizen groups are often perceived negatively because the public authorities and aid organizations have not planned for the emergent behavior and therefore cannot 'control' as well as manage the groups during events of disaster (Stallings & Quarantelli, 1985).

Identifying, integrating and managing emergent citizen groups in time-critical and uncertain situations are challenging. There often is neither a clearly designated leader, nor a formally assigned liaison or intermediary person for dealing with public authorities and appointed aid organizations which hampers cooperation from the official's perspective (Stallings & Quarantelli, 1985). As Stallings & Quarantelli (1985) argue, those characteristics make it difficult for others outside of the emergent citizen groups to develop relationships with them. A lot of (inter-)national research projects already aimed at tackling these issues:

Acronym	**Focus**	**Period**	**Website**
A4A: Alert for All	Development of People-Centered Early Warning Systems paradigm	2011-2013	www.alert4all.eu
ACRIMAS: Aftermath Crisis Management System-of-Systems Demonstration	Developing systematically crisis management systems, procedures and technologies in Europe	2014-2017	www.acrimas.eu/
AHA: Automatisiertes Helferangebot bei Großschadensereignissen	Development of a smartphone application for matching volunteers with help requests	2014-2017	www.projekt-aha.hs-ruhrwest.de
EMERGENT: Emergency Management in Social Media Generation	Developing concepts for using social media during crisis management	2014-2017	www.fp7-emergent.eu/
Ensure: Verbesserte Krisenbewältigung im urbanen Raum durch situationsbezogene Helferkonzepte und Warnsysteme	Warning and mobilizing volunteers with specialized knowledge in situ	2013-2016	www.ensure-projekt.de
Hands2Help: Resiliente Prozesse durch	Warning and mobilizing volunteers	2013-2016	www.informationsmanagement.wiwi.u

IT-Infrastrukturen	with specialized knowledge in situ		ni-halle.de/projekte/hands2help/
INFOSTROM: Lernende Informationsinfrastrukturen im Krisenmanagement am Beispiel der Stromversorgung	Developing a security arena as a cooperation platform between emergency services and the public	2010-2013	www.infostrom.org
INKA: Professionelle Integration von freiwilligen Helfern in Krisenmanagement und Katastrophenschutz	Developing concepts for integrating unaffiliated volunteers into official crisis management	2012-2015	www.inka-sicherheitsforschung.de/
KOKOS: Unterstützung der Kooperation mit freiwilligen Helfern in komplexen Einsatzlagen	**Developing concepts and tools for cooperation between emergency services and volunteers**	**2015-2018**	**www.kokos-projekt.de/**
KUBAS: Koordination ungebundener vor-Ort-Helfer zur Abwendung von Schadenslagen	Developing a system for automatic communication and registration of volunteers	2016-2019	www.kubas.uni-halle.de/
PEP: Public Empowerment Policies for Crisis Management	Developing public empowerment policies between emergency services and citizens	2012-2014	www.crisiscommunication.fi/pep
PRAKOS: Praktiken und Kommunikation zur aktiven Schadensbewältigung	Communication concepts between emergency services and the public	2014-2017	www.vfdb.de/forschung/prakos/projekt
RESCUER: Reliable and intelligent use of crowdsourcing information for Crisis Management	Developing technology for reliable and intelligent analysis of crowdsourcing information	2013-2016	www.rescuer-project.org
RESIBES: Resilienz durch Helfernetzwerke zur Bewältigung von Krisen und Katastrophen	Developing a network of volunteers that can be activated during emergencies	2016-2019	http://resibes-osm.cs.upb.de/
TEAMWORK: Krisensimulation für die Zusammenarbeit von Einsatzkräften und Bevölkerung	Using serious games to support training concepts	2016-2019	http://www.teamworkprojekt.de/

The research presented in this paper was conducted in the project KOKOS and, as we will show, the concept of intermediary organizations could establish the organizational framework for an appropriate cooperation between emergent citizen groups as well as public authorities with security responsibilities and aid organizations. Thereby, the concept of intermediary organizations offers an indirect way of embedding spontaneous and unaffiliated volunteers into crisis management systems compared to a more direct alternative as described e. g. in ISO/DIS 22319:2016 “Guidelines for planning involvement of spontaneous volunteers”, ISO, 2016).

EMPIRICAL STUDY

To get first insights into emergent citizen groups as well as their relation to official crisis management processes, we conducted an empirical study consisting of two case studies. Case 1 addresses events of flooding, case 2 investigates the migrant crisis, focusing on the situation at a German and an Austrian train station in summer 2015. Within the case studies, we employed in-depth interviews (n=13, flooding: n=4, migrant crisis: n=9). Interviewees were experts from public authorities with security responsibilities, representatives from aid organizations and engaged citizens.[1] The semi-structured interviews were conducted from September 2015 until February 2016 and addressed the duties and responsibilities of the public authorities, organizations and persons in general as well as in the respective crisis event, the course of action during the respective crisis and the cooperation with other organizations as well as engaged citizens. In addition, the interviewees were asked to assess the course of action as well as the cooperation with others in the respective crisis event. Subsequently, the recordings were transcribed verbatim and thematically coded following the four steps approach applied by Hopf et al. (1995, described in Kuckartz, 2010). In addition, the cases of flooding and migrant crisis were analyzed and compared based on seven pre-defined criteria (actors, experience of actors, organizational structure, direction of control, involvement of spontaneous and unaffiliated volunteers, utilization of civil engagement, and form of cooperation).

Case 1: Flooding (in Germany)

In events of flooding, roles and responsibilities are clearly defined in Germany. In general, the fire brigade is in charge of disaster control and crisis management and is supported by other (honorary) aid organizations (e. g. German Red Cross (DRK) or the federal agency (THW)) if needed. The cooperation is clearly structured and follows a hierarchical «command-and-control» approach. Decisions are made by the emergency task force and are carried out by subordinated teams. The firefighters are usually quite experienced and trained to manage floods, especially in regions where events of flooding occur quite frequently. In some cases, spontaneous and unaffiliated volunteers offer their resources and support but usually the cooperation is not institutionalized and works, if at all, on call. In the interviews, representatives from public authorities with security responsibilities and aid organizations claimed that embedding spontaneous and unaffiliated volunteers into crisis management systems in general leads to high communication and coordination efforts which cannot always be achieved. As a consequence, the resources and capabilities of those volunteers usually are not fully utilized.

However, the case of Wertheim, a city in the region of Bavaria in Germany, indicates that this does not have to be a rule: As Wertheim gets struck by flooding recurrently an emergent group of citizens has joined forces and founded the association *Bürgergemeinschaft Hochwasser Wertheim e. V. (BgHW).* The association aims at supporting the public authorities, especially the fire brigade, as well as aid organizations in case of flooding in Wertheim, is open to all community members and interested citizens and is highly acknowledged by public authorities. In order to allow and support close collaboration and exchange of information in the event of flooding, the fire brigade has invited representatives of the association to become permanent members of the emergency task force. Thereby, the representatives of the association get first-hand information by the authorities which they can use to coordinate the activities of their members. In addition, the representatives can provide first-hand information from the civil society to the authorities. Hence, the volunteers get informed and appointed to those activities where their help is needed the most and the public authorities are aware of the public needs and issues. With this special practice of cooperation, closing of ranks between public authorities with security responsibilities as well as aid organizations and the civil society is ensured and the resources of the civil society are utilized more efficiently. As a result, both the authorities as well as the members of *BgHW* evaluate the cooperation as successful, well-rehearsed and enduring.

Case 2: Migrant Crisis at (German and Austrian) Train Stations

The case of the migrant crisis presents itself quite differently. In the summer of 2015, hundreds and thousands of refugees arrived each day in Europe. At the train stations e. g. in Germany and Austria hundreds of refugees arrived daily in trains which were charted by the authorities of other European countries, e. g. Hungary, to

[1] For case study 1 (flooding in Germany), we interviewed a local representative of a public authority with security responsibilities, a head of unit of a city administration, the founder of an initiative brokering spontaneous volunteers to aid organizations, and the chairman of the association BgHW.

For case study 2 (migrant crisis at German and Austrian train stations), we interviewed a spokesman of a public authority with security responsibilities, a division and a project manager as well as a coordinator for volunteers of three aid organizations, two regular employees of aid organizations, two spontaneous volunteers and founders of an intermediary organization as well as a priest coordinating voluntary programs.

distribute the asylum seekers within the European Union. Media have drawn considerable attention to this political and social turmoil. As a result, hundreds of spontaneous and unaffiliated volunteers turned up at the train stations to welcome and support the refugees. Interviewees from both sides, representatives from public authorities as well as engaged citizens, perceived the situation at the respective train station to be somewhat chaotic at the beginning. Aid organizations and public authorities with security responsibilities were on site, but especially in the first hours their roles and responsibilities were not clearly defined at all. Interviewees from public authorities and aid organizations in Germany claimed that clear political directives were missing. The interviewed citizens explained that the spontaneous and unaffiliated volunteers realized this shortcoming and tried to bridge the gap by supplying the refugees with food, clothing, and information themselves. They also shared that most of the volunteers had little to no experience in humanitarian aid or working with refugees. Yet, the volunteers worked on call and decided intuitively what to do next. According to the interviewed citizens as well as representatives from public authorities, the activities were organized and directed bottom-up – and unfortunately bypassed the public authorities and appointed aid organizations quite often. On the other hand, the interviewed citizens accused the public authorities who have often failed to involve the volunteers into their activities on site and to institutionalize cooperation, especially in the beginning. As a result, both sides described that they experienced some frustration particularly during the first hours and days of activity at the train stations.

However, the examples of Frankfurt, Germany, and Vienna, Austria, show that collaboration can work even in this novel and chaotic kind of situation. In both cases, the spontaneous and unaffiliated volunteers have organized themselves over time and have built a network (called *Second Planet* in Frankfurt and *Train of Hope* in Vienna) with clear structures, roles and responsibilities as well as communication channels. Once identified by the public authorities and aid organizations as a properly functioning emergent citizen group which is able to coordinate and manage itself, the authorities pursued cooperation and started to work closely together to achieve common goals. Both authorities as well as emergent citizen groups in Frankfurt and Vienna described the teamwork as successful, effective and amicable once the chaotic phase with unclear roles and responsibilities was overcome. Due to this positive experience and in order to further support the social integration of refugees, *Second Planet* has in the meanwhile registered as an association.

INTERMEDIARY ORGANIZATIONS: AN ORGANIZATIONAL CONCEPT

In Wertheim (flood), Frankfurt and Vienna (migrant crisis) public authorities with security responsibilities and aid organizations successfully integrated the public in disaster control by outsourcing the registration, coordination and management of the engaged citizens to a third organization. The registered association *BgHW* bundles the resources of the engaged citizens, coordinates their activities, and matches supply and demand for assistance. Thereby, *BgHW* offers a kind of a service to the authorities. In the migrant crisis, the emergent citizen groups *Second Planet* and *Train of Hope* have demonstrated to be effective intermediary organizations, too, taking over registration, coordination and management of volunteers and, thereby, functioning as interface between the public authorities and the volunteers. Drawing on these empirical findings and to promote the transfer of the concept to other use cases, we have derived, developed and defined the concept of integrating unaffiliated and spontaneous volunteers in crisis management processes (for Germany) through an intermediary organization as follows:

> « The organizational concept of intermediary organizations describes a form of structured involvement of the public into crisis management systems for the purpose of preventing and/or managing a crisis situation. In this form, the public authorities with security responsibilities and aid organizations outsource the coordination and management of individual (e.g. spontaneous, unaffiliated volunteers) and collective volunteers (e.g. associations, enterprises) to a third party in order to conserve its own resources while, at the same time, making the competencies and capacities of the civil society accessible.
>
> An intermediary organization supports the prevention and/or management of a crisis on behalf of the authorities and cooperates with public authorities with security responsibilities and aid organizations for this purpose. It assumes the task of structuring and coordinating already existing, unaffiliated civil engagement before and/or in a crisis situation and, if necessary, creating a point of entry for new, spontaneous engagement. In this way, the intermediary organization supports the professional integration of low-threshold forms of civil engagement into crisis management systems which are independent of a long-term honorary office.
>
> To effect insurance for all (temporary) members, the intermediary organization has to be (informally) designated as such by the Lower Disaster Prevention Agency and/or the responsible public authority or aid organization before or during a concrete crisis situation. This informal act promotes an intermediary organization to a temporary public assistant, subordinated to the Lower Disaster Prevention Agency and/or the public authority or aid organization in charge. With this, intermediary organizations do not have to cover for damages caused by them negligently. Instead, it becomes an official liability. In addition, intermediary organizations and their

members profit from statutory accident insurance. In case of malpractice, the Lower Disaster Prevention Agency and/or the responsible public authority or aid organization is lawfully authorized to dismiss the respective intermediary organization or individual. In order to be on the safe side with regard to legal aspects, registration of the members of intermediary organizations is advisable but not mandatory.[2]

An intermediary organization can emerge from an already existing civil society structure (such as a sports club or a church community) or can be newly founded for the purpose of preventing and/or managing a crisis situation. It can emerge from a citizen's initiative or be initiated by the authorities. In any case, an intermediary organization is a voluntary association of individual and/or collective civil society actors and acts as an intermediary between public authorities and the civil society. Thereby, it sets its focus on embedding the civil society as a resource and an active partner into crisis management systems. »

In practice, *BgHW*, *Second Planet* and *Train of Hope* have demonstrated ways in which an intermediary organization can emerge, structure and organize itself and support embedding emergent citizen groups and other unaffiliated volunteers into crisis management systems. In all three cases, public authorities with security responsibilities and aid organizations have benefited from the cooperation with the intermediary organization to such extent that they were able to access the diverse resources and competencies of the civil society without having to devote own resources to the coordination of the volunteers. Instead, the authorities only had to ensure the exchange with a contact person at the intermediary organization which served as a multiplier to the volunteers. Citizens also benefited from the intermediary organization as a dedicated contact point which they could turn to for engagement in a crisis situation. Also, the intermediary organizations assumed the role of a social and cultural bridge between the «command and control» approach of the public authorities and aid organizations and the flat hierarchies, the spontaneous and adventurous spirit of the volunteers.

COLLABORATIVE RESILIENCE: IT-TOOLS TO SUPPORT COLLABORATION BETWEEN AUTHORTIES, INTERMEDIARY ORGANIZATIONS AND VOLUNTEERS

To support the development and operation of intermediary organizations as well as their coordinative work in crisis situations, we have developed a public display application, called City-Share (Ludwig et al., 2016). The aim of City-Share (Figure 2) is to crowdsource relief activities to unaffiliated volunteers and emergent citizen groups from a place-centric perspective within neighborhoods. The public display offers functionality to support self-help amongst the civil society itself mediated by intermediary organizations simultaneously supporting the alignment of voluntary activities with those of the public authorities with security responsibilities as well as aid organizations.

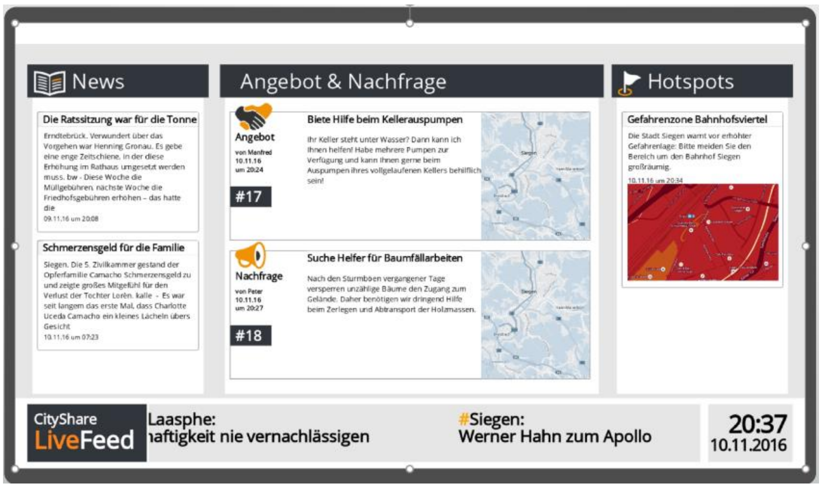

Figure 2: Situated crowdsourcing for managing voluntary tasks (Ludwig et al., 2016)

The public display application should be placed at central locations e.g. train stations or other highly frequented places to reach a large audience and serve as a first contact point for spontaneous and unaffiliated volunteers. A network of such displays spread through an entire city poses an effective communication infrastructure for

[2] For further legal information regarding Germany, please see the work of Erkens (2016a; 2016b).

coordinating activities of emergent citizen groups. In case of infrastructure breakdown such as loss of internet or electricity, the system is able to partly continue its work. To prevent power outage for a while, uninterruptible power supply has to be provided, either via placing the display within a hospital or another institution that provides this kind of service or separate devices at the respective place have to be installed. In case of internet breakdown, the system is still able to provide a local Wi-Fi for interaction. The information will then be transferred via the users' smartphones when they pass by other users or public display systems. To support coordination between spontaneous and unaffiliated volunteers and local (affected) citizens, the public display offers the sharing of requests for help as well as the offering of support as a main functionality. Spontaneous and unaffiliated volunteers are able to answer requests from affected citizens (or any other organization) describing how many they are and what they are capable of or willing to do, where and how long they are available, etc. This kind of coordination of spontaneous and unaffiliated volunteers is supplemented by local "hotspots" that serve as physical contact points of responsible public authorities or aid organizations as well as news from various sources such as newspapers and social media. Social media are usually used for coordinating relief activities during crisis situations wherefore spreading it to the public helps raising awareness for voluntary activities. Additionally, the public display offers a live feed at the bottom of the screen to visualize important news (e. g. created by intermediary organizations) or warnings (created by public authorities).

In terms of the control center, public authorities with security responsibilities and aid organizations are able to configure what news channels or hashtags to subscribe to and what local hotspots should be presented. They can create warnings as well as any other type of message to be shown in the news feed. While using the public display, public authorities can increase awareness for their own local activities as well as align their own activities with those of the volunteers – and vice versa. By monitoring the public display, public authorities get awareness for e.g. loosely structured, emergent citizen groups that are very active or seem to be plausible candidates to be promoted to intermediary organizations.

In addition to the public display system, the socio-technical concept 'Security Arena' (German: Sicherheitsarena) provides organizational and communicative-medial measures to improve 'readiness', 'preparedness' as well as 'copability' in events of crisis by providing public authorities and the general public a platform to cooperate and exchange ideas in everyday life (Ley *et al.*, 2014; Pipek *et al.,* 2013). By inviting e. g. fire brigades, aid organizations, private initiatives and associations, companies, men, women, press and media to discuss ideas with regard to their respective neighborhood or local events, the 'Security Arena' institutionalizes the cooperation of so-called local security-communities and the public, enabling the emergence of cooperative relationships which can prove helpful in events of crisis. By institutionalizing cooperative relationships in everyday life, joint work routines, patterns of communication and structures of cooperation can be established on an inter-organizational level, paving the way for joint planning, acting and learning also in crisis situation. Specifically, the 'Security Arena' aims at offering communicative-medial instruments to facilitate and promote the development of sustainable (dialogical) communication practices, to share information and to establish a joint information management, and to foster cooperative learning processes as well as skill development. Ultimately, 'Security Arena' strives to increase collaborative resilience by integrating and embedding the public into crisis management systems.

The basic component of the 'Security Arena' concept is a web-based inter-organizational social network called SiRena (Figure 3), providing various modules to support cooperation and collaboration going beyond common social media functionalities. Besides user profiles, access control, and basic communication functionalities, groups are the main element of the system. Providing a platform to meet fellow citizen, exchange and discuss ideas and jointly work on projects, this SiRena functionality especially encourages the emergence of citizen groups. Thereby, SiRena offers both open and closed groups. Open groups are accessible to all SiRena members, allowing them to follow and engage in ongoing discussions and see who the other members of the group are. In closed groups, interested SiRena members need to request access or have to be invited by a group member. This kind of group is designed to discuss sensitive matters and content where data protection is the key. In crisis situation, this feature is especially valuable. In addition to groups, other collaborative functionalities are implemented e. g. collaborative file handling (including the creation, management, editing and exchange of documents, media and files), a joint calendar, a discussion forum and an activity stream that filters existing activities based on defined tabs. To communicate, the system provides both an internal messaging system and a chat. The access to SiRena is designed as a walled garden which means that it requires an invitation by a SiRena member.

Based on this set of functionalities, SiRena supports (a) the interlinkage of different organizations in a safe environment, (b) informal communication, (c) the search for experts, (d) document-sharing between different work groups and organizations, (e) the aggregation and presentation of external information, as well as (f) the development of joint situation pictures. Originally customized to facilitate collaboration between public authorities with security responsibilities and solo helpers as well as emergent citizen groups, SiRena can also support the coordination work of an intermediary organization with a much higher organizational level as the functionalities are compatible.

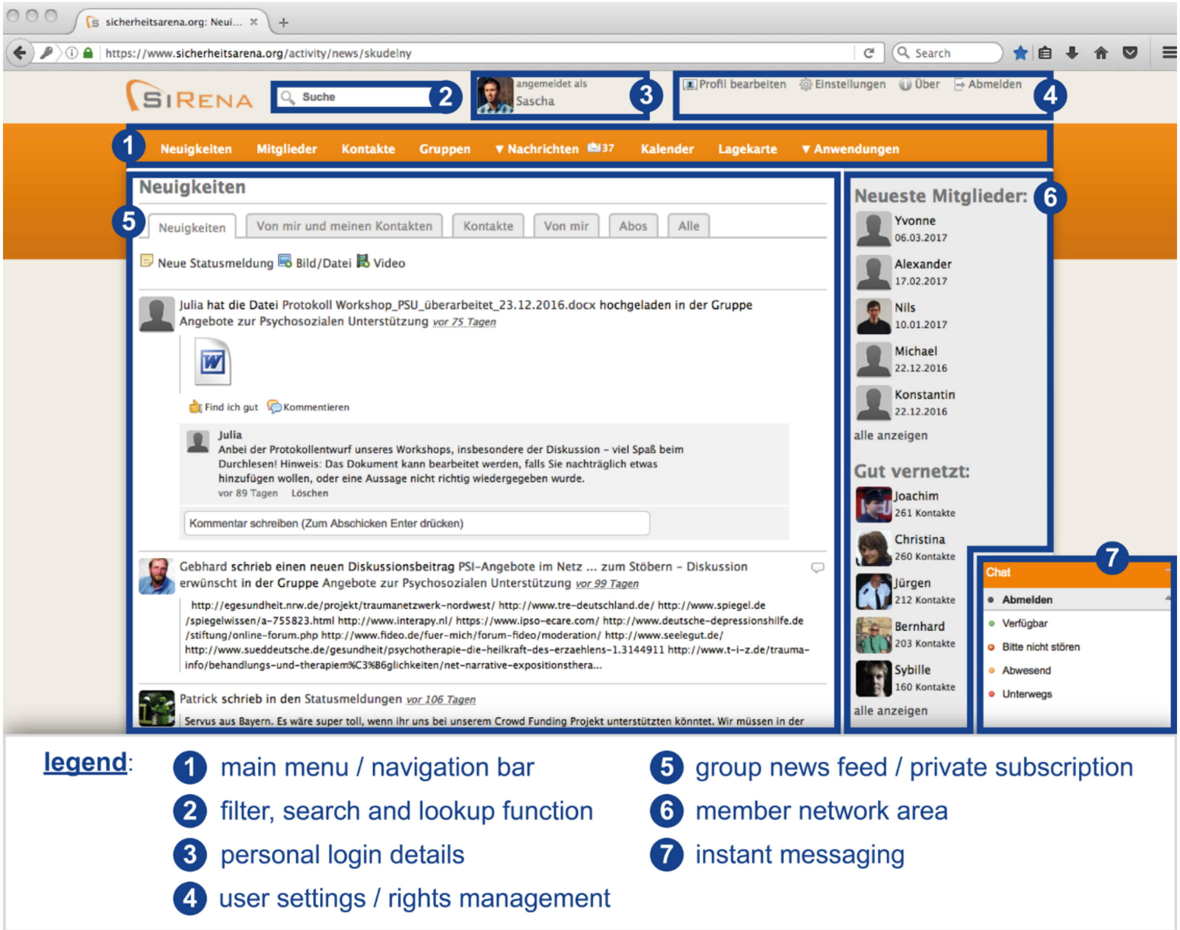

Figure 3: SiRena – Social network offering collaborative functionalities (own illustration)

The concept of intermediary organizations and its supportive (often crowd-based) tools such as the situated public display application City-Share or the inter-organizational platform Security Arena encompass different levels of responsibility (volunteers, official) as well as different types of located information sources. Intermediary organizations can therefore foster community's disaster resilience, especially when focusing on the situated kind of collaborative resilience emerging between professional public authorities with security responsibilities, emergency services and private aid organizations as well as the spontaneous volunteers. 'Disaster resilience' can be understood as the "ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stress – such as earthquakes, drought or violent conflict – without compromising their long-term prospects" (Department of International Development, 2011).

Based on the concept of disaster resilience (Department of International Development, 2011), collaborative resilience aims at supporting disaster resilience by a strong cooperation between all involved stakeholders such as public administration, public authorities with security responsibilities and aid organizations, but also affected citizens as well as spontaneous volunteers (Goldstein, 2011). The intermediary organizations could serve as a cooperative and vital link between those stakeholders. Establishing collaboration through intermediary organizations between the "private and public sectors could improve the ability of a community to prepare for, respond to, and recover from disasters" (National Research Council, 2011).

CONCLUSION

In literature, research and practice, numerous recommendations and approaches can be found on how to embed the public and especially spontaneous and unaffiliated volunteers in disaster control and crisis management. And the technical tools to support cooperation are manifold, too. The concept of collaboration through an intermediary organization is intended to describe one possible way, bridging the cultural gap between public authorities with security responsibilities and aid organizations on the one hand, and the engaged citizens on the other. The concept of intermediary organization thus provides an alternative to the direct embedment of spontaneous and unaffiliated volunteers in the structures of the civil protection and humanitarian support organizations (as e. g. described in ISO/DIS 22319:2016 "Guidelines for planning involvement of spontaneous volunteers", ISO, 2016).

Of course, the concept of embedding the engaged public in disaster control through intermediary organizations comes not without risk. In order to enable public authorities and aid organizations to work together with an intermediary organization, the (political) framework has to be defined, processes and rules of cooperation have to be created, tasks specified and roles clarified. In addition, scenarios and fields of application where this way of cooperation is useful need to be identified. Further, the obstacles that come with organizational change must be overcome by public authorities and aid organizations. To support this process, it is necessary to make suitable organizational and technological tool kits available to the authorities and aid organizations. This includes context-sensitive instructions how to design processes of collaboration as well as appropriate training concepts to prepare the authorities and their members to cooperate with intermediary organizations. In addition, it is necessary to provide a comprehensive manual for intermediary organizations and their members which enables them to carry out specific tasks ad-hoc in a concrete crisis situation and in line with the principles of disaster control.

ACKNOWLEDGMENTS

We thank the German Federal Ministry of Education and Research (BMBF) for funding and supporting the presented joint research project KOKOS („Supporting Collaboration in Complex Crisis Situations", FKZ 13N13559 - 13N13561). In addition, we thank our interviewees and associated project partners for their efforts and input. In various discussions and workshops, disaster control practitioners contributed their expertise, enabling application-driven research. Thank you for that. Some of the interviews were carried out by research assistants. Thank you all for your efforts.

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Study on Integrated Risk-Management Support System

− Application to Emergency Management for Cyber Incidents −

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ABSTRACT

We have been studying the standardization of an emergency-management support system mainly for natural disasters at the local-government level. The system provides information from three viewpoints, “Plan: What should we do?”, “Do: What are we doing?”, and “See: What kind of situations are we in?” to support decision making at an emergency operations center. Rapid and accurate judgment prevents the occurrence of new damage and the expansion of damage, and as a result resilience will increase. We investigated its applicability to emergency management for cyber incidents through a cyber-defense exercise.

Keywords

Emergency Management, ISO22320, Incident response, Emergency Operations Center

1. BACKGROUND AND PURPOSE

Damage caused by cyber incidents has recently become a serious problem. In 2015, there was leakage of subscriber information from the Japan Pension Organization, which became a major problem in Japan. Not only information leaks but also incidents that directly affect social life have occurred. For example, due to cyber attacks, the centrifuge of a nuclear power plant temporarily became unusable, large-scale blackouts occurred, and the computer networks of financial institutions became paralyzed, enabling illegal remittances (Research Group to make Resilient Society, 2016).

In 2014, The National Center of Incident Readiness and Strategy for Cybersecurity (NISC) of Japan defined “critical infrastructure” including 13 sectors such as “information communication”, “financial”, and “electric power”. To prevent IT disruption caused by natural disasters or cyber incidents from having a serious effect on infrastructure, action plans were set up to reduce the occurrence of IT faults and to promptly restore services (National center of Incident readiness and Strategy for Cybersecurity, 2016).

Many cyber-attacks were reported in the London 2012 and Rio 2016 Olympic Games, and it is expected that they will further increase in the Tokyo 2020 Games. Various risks, such as natural disasters, infectious diseases, and incidents on information systems or lifelines, are defined in the international standard ISO 20121 “Event Sustainability Management Systems” (ISO20121, 2012).

Thus, important social infrastructures being damaged by cyber attacks or multiple incidents occurring in combination at a big event may increase in the future. If each organization responds individually and separately when an incident occurs, incident-response activities may be inefficient. Therefore, it is necessary to standardize such activities. It is important for related organizations to cooperate and collaborate to address incidents effectively and efficiently (Hayashi, 2014).

We have been developing management flow and an information and communications technology (ICT)-integrated emergency-management support system as a countermeasure against natural disasters on the local-government level (Kosaka et al., 2014). We confirmed its usefulness over several years at disaster-response trainings (Higashida et al., 2012; Ichinose et al., 2015).

In this paper, we aim to evaluate the applicability of our system to the cyber field, through cyber defense exercises and interviews, in order to enhance resilience in the cyber field.

2. ELEMENTS OF EFFICIENT RISK MANAGEMENT

2.1 Standardization of risk management

The risk-management cycle consists of four stages; preparation (Plan), incident response (Do), review (Check), and plan modification (Action), as shown in Fig. 1 (Nakajima et al., 2013). We preliminarily take countermeasures against an assumed risk and respond to it when an incident occurs. We then analyze and evaluate the problems and issues through review then take measures to prepare for the next incident. The decision-making process is called the observe, orient, decide, act (OODA) loop (Tanaka, 2016) proposed by the air force Colonel John Boyd of the US military is applicable for the Do stage. In International Standard Organization (ISO) 22320 on incident response, the decision-making process is regulated, as shown in Fig. 2, as a command-and-control process. In other words, we collect and share information on the damage and countermeasures related to an incident, analyze and evaluate the collected information, predict the future, formulate a plan based on the results, and finally make decisions and share them with related parties. Then we will take action according to the decisions. In the standard, the following three points are summarized as the minimum necessary requirements, and they can be applied to any incident.

A) Requirements for command and control
B) Requirements for activity information
C) Requirements for cooperation and coordination

Cooperation is necessary in each step of Fig. 2. In the standard, “cooperation” and “coordination” are clearly distinguished. "Cooperation" means having a common purpose for multiple organizations to achieve, and "coordination" means synchronizing actions to achieve common objectives agreed upon by multiple organizations. When a wide variety of organizations gather to address an incident, it is important to clarify "objectives" and to synchronize their actions, that is, to manage the incident-response activities. The basis of ISO 22320 is the framework called the Incident Command System (ICS) formulated in the United States (Deal et al., 2012). The Operational Planning “P” is defined as concretizing the command and control process of ISO 22320 (Fig. 3). The lower half of the “P” shows the preparation before incident occurrence and the initial response, and the loop part shows that the cycle for information collection, decision making, etc… is repeated. By clarifying the process in this way, it may be possible to make decisions efficiently and enable cooperation among related organizations. It is necessary to clarify the decision-making process by stipulating concrete conferences in accordance with the organizational structure.

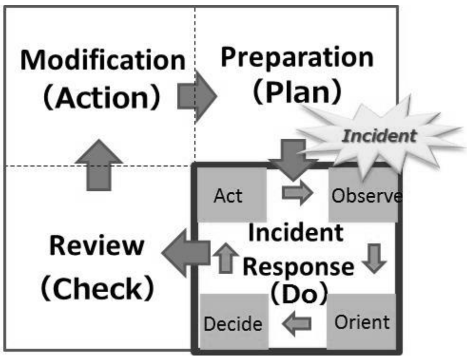


Fig. 1 Cycle of risk management

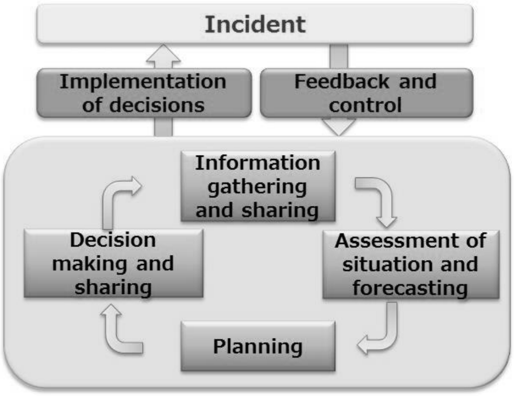


Fig. 2 Command-and-control process

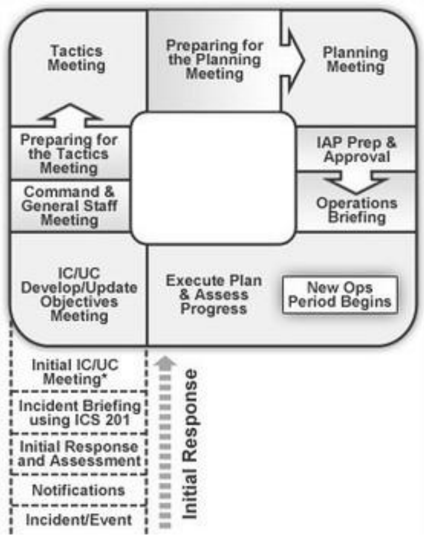


Fig. 3 Operational Planning "P"

2.2 Smooth communication and unification of situation recognition

In addressing incidents, it is necessary to unify situation recognition among related members and respond by efficiently communicating according to the standardized management flow described in the previous section. There are two types of incident-response activities, typical and atypical (Fig. 4). Typical activities have been experienced several times in the past and can be standardized. By preparing incident-response plans in advance, delegation of authority to staff in the field and support by volunteers and external staff, etc… can be facilitated and efficiency can be improved.

However, new problems that have never been experienced before will also occur. In such a case, it is necessary to share situation recognition among related members and to make a new response plan. Therefore, it is important to know how to standardize the incident-response activities, delegate authority to the site, and secure time to solve new problems.

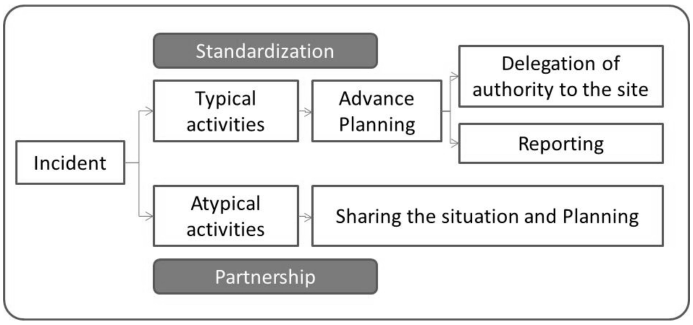


Fig. 4 Classification of incident-response activities

A requirement in ISO 22320 Section 2.1 B) states that "it is necessary to specify the purpose of the activity and to clarify what kind of information is required for that purpose". It is necessary to collect static information, e.g., geographical data, in advance then collect as much dynamic information, e.g., damage situation, as possible using prepared formats. To achieve this, an ICT system is required. We divide the information handled in an incident response into two types, fixed format and free format, based on the research results thus far. For fixed-format information, information to be collected is decided according to the purpose, and it is easy to collect necessary information by preparing a particular format in advance. It is also possible to compile and consolidate collected information, so an overview of the overall situation, that is, unification of situation recognition, i.e., a common operational picture (COP) among related members, may be possible. Free-format information, on the other hand, is communication in a free-description format, consisting of instructions and responses to them. During an incident-response training in Kashihara-city, Nara Prefecture in 2013, it was observed that free-format information occupied 74% of the information handled in a web-based communication system. Therefore, we believe it is necessary to use both fixed- and free-format information and be able to obtain an overview of the incident as a whole, such as damage and response situations.

The Interoperability Continuum formulated by US Department of Homeland Security (DHS) consists of five factors for effective incident response. They are “Governance”, “Standard Operations Procedure (SOP)”, “Technology”, “Training & Exercises”, and “Usage”. In other words, after establishing governance and SOP, an ICT system that supports crisis-response activity based on these factors is necessary.

2.3 Proposed Integrated Risk-Management Support System

The proposed integrated risk-management support system is mainly for effective incident response, and it can also be applied to a larger risk-management cycle, as shown in Fig.1, by reviewing the results of training or actual incident response. In this system, the gathered information can be browsed from the information aggregated on Plan, Do, and See screens of the ICT system, and the system supports efficient and effective decision making and cooperation between organizations, which leads to improved resilience. On the Plan screen, one can confirm “What should be done now?”, on the Do screen “What is being executed now?”, and on the See screen “What is the situation now?”

2.3.1 Plan Screen

The Plan screen is shown in Fig. 5. It shows the Operational Planning “P” with a checklist showing who should do what at each step of the “P”. Even an inexperienced staff member can understand "what to do now" and "what to do next". It also provides the goals decided by the head of the organization, meeting schedule, and meeting materials, manuals, etc...

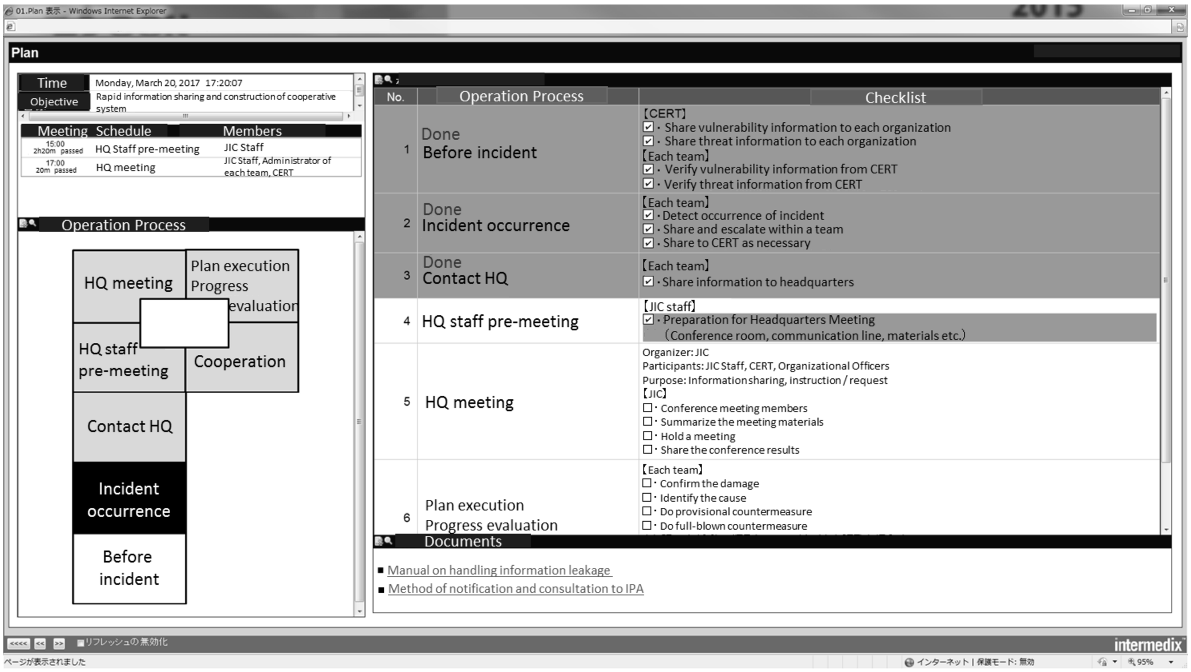


Fig. 5 Plan screen

2.3.2 Do Screen

The Do screen is shown in Figs. 6 and 7. Figure 6 is a list of messages that contain atypical information, and messages between organizations are displayed in chronological order. Each message contains a message ID, levels of importance and emergency, status (ex. completed or no completed), date and time, sender, receiver, subject, and contents. Due to the color coding according to the level of importance, emergency, and status, important messages that need to be read can be distinguished immediately. Figure 7 is a list of cyber-threat information, which is also atypical information.

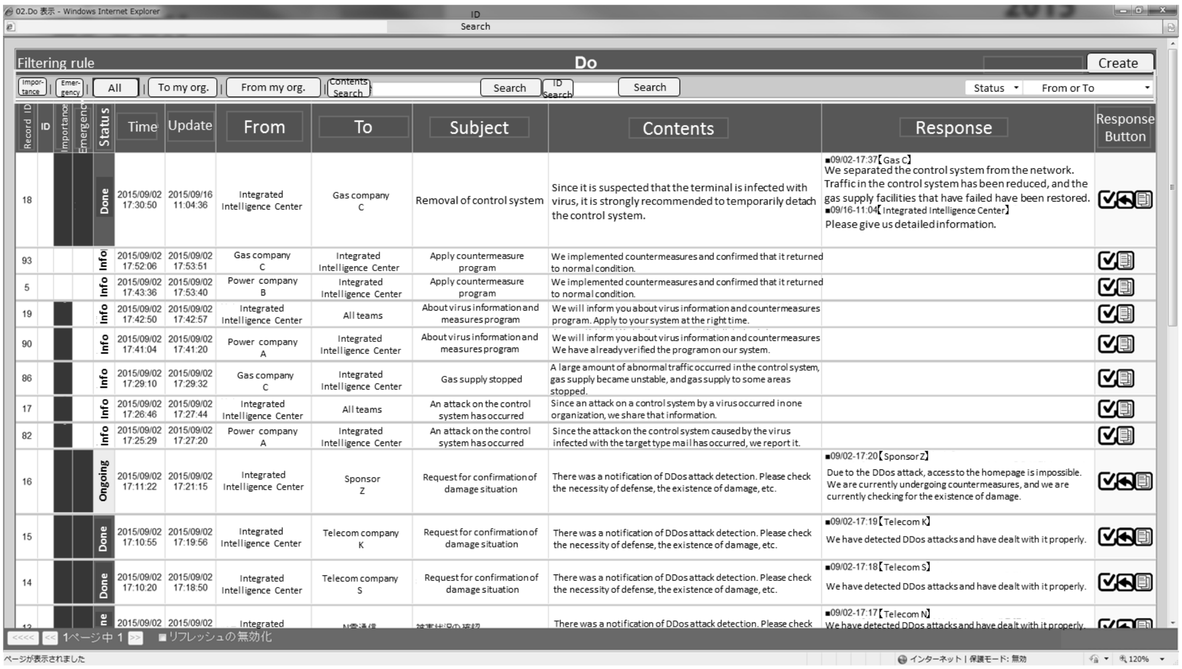


Fig. 6 Do screen (List of messages)

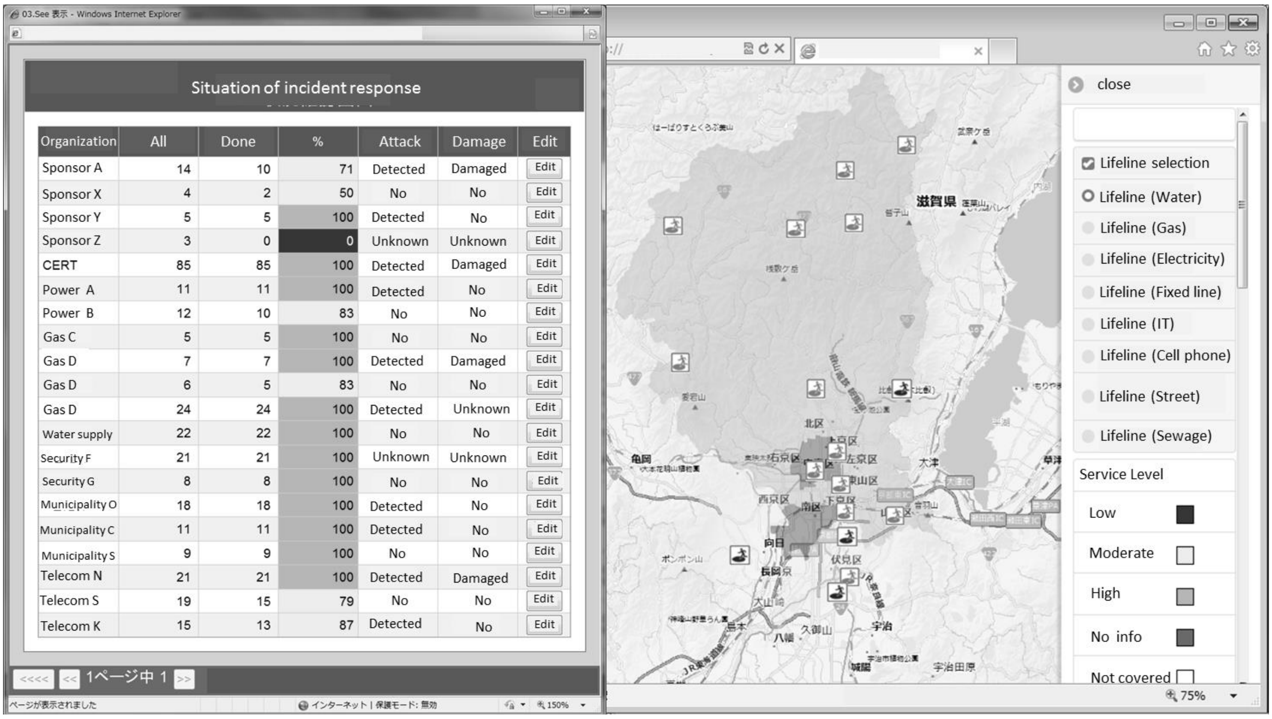
Threat Information

ID	Time	type	Subject	Ver.	CVE	Scope of Influence	Summary	Threat	Ref.
6	10/08 18:20:32	Warning	A vulnerability in which a third party can execute arbitrary code on the Apache http server	1st. report	2014-9999	・Apache http server 2.4系：2.4.0～2.4.9 ・Apache http server 2.2系：2.2.0～2.2.29 ・Apache http server 2.0系：2.0.0～2.0.65 ★Apache http server 1.3系：1.3.0～1.3.42 The above versions are affected. The information of ★ is newly confirmed by CERT this time. The effect on other versions will continue to be investigated.	There is a possibility that a third party can execute arbitrary code.	There is a possibility that a third party can execute arbitrary code. CERT has already confirmed an exploit code which is public.	Ref.
5	10/08 17:38:08	Warning	A vulnerability in which a third party can execute arbitrary code on the Apache http server	2nd. report	2014-9999	・Apache http server 2.4系：2.4.0～2.4.9 ・Apache http server 2.2系：2.2.0～2.2.29 ・Apache http server 2.0系：2.0.0～2.0.65 The above versions are affected. The effect on other versions will continue to be investigated.	There is a possibility that a third party can execute arbitrary code.	There is a possibility that a third party can execute arbitrary code. CERT has already confirmed an exploit code which is public.	Ref.

Fig. 7 Do screen (Threat information)

2.3.3 See Screen

The See screen is shown in Fig. 8. The display is color-coded so that the overall situation can be easily confirmed. We refer to the color code of ISO 22324, i.e., “red” danger, “green” safe, and “yellow” moderate. It is easy to compile and summarize fixed-format information, so it is possible to unify recognition among members by visualizing the overall situation in a tabular form or on a map.



Organization	All	Done	%	Attack	Damage	Edit
Sponsor A	14	10	71	Detected	Damaged	Edit
Sponsor X	4	2	50	No	No	Edit
Sponsor Y	5	5	100	Detected	No	Edit
Sponsor Z	3	0	0	Unknown	Unknown	Edit
CERT	85	85	100	Detected	Damaged	Edit
Power A	11	11	100	Detected	No	Edit
Power B	12	10	83	No	No	Edit
Gas C	5	5	100	No	No	Edit
Gas D	7	7	100	Detected	Damaged	Edit
Gas D	6	5	83	No	No	Edit
Gas D	24	24	100	Detected	Unknown	Edit
Water supply	22	22	100	No	No	Edit
Security F	21	21	100	Unknown	Unknown	Edit
Security G	8	8	100	No	No	Edit
Municipality O	18	18	100	Detected	No	Edit
Municipality C	11	11	100	Detected	No	Edit
Municipality S	9	9	100	No	No	Edit
Telecom N	21	21	100	Detected	Damaged	Edit
Telecom S	19	15	79	No	No	Edit
Telecom K	15	13	87	Detected	No	Edit

Fig. 8 See screen

3. VERIFICATION IN CYBER-INCIDENT EXERCISE

We evaluated the effectiveness of our system in a cyber-incident exercise involving several private companies.

The main purpose of the exercise was to verify the content of an incident-response manual. In the exercise, the Do screen of the system was used as a substitute for e-mail, which is often used by participants, and we verified that communication between organizations can be done smoothly. Smooth communication enables prompt information sharing. Especially in cyber incident response, unlike natural disasters, situation is hard to see, so sharing information on attacks, damage, and countermeasures is very important. It suppresses the occurrence of new damage and the expansion of damage. That will lead to improved resilience.

We created two kinds of evaluations, i.e., analysis of the Do screen logs recorded in the system and the results of a questionnaire given to the participants. The log analysis of the Do screen is for quantitative evaluation of communication inside and outside the organization. The questionnaire is for qualitative evaluation and gathering comments on the following items.

[Q1_1] Evaluate communication through free-format description on a 5-point scale (very useful, useful, ordinary, not very useful, useless)

[Q1_2] Write your comments on communication through free-format description.

[Q2_1] Evaluate "threat information/situation view" screen on a 5-point scale (very useful, useful, ordinary, not very useful, useless)

[Q2_2] Write your comments regarding "threat information/situation view" screen.

[Q3_1] Write your comments regarding what is good about the system.

[Q3_2] Write your comments regarding what is bad about the system.

4. Results and Discussion

The cyber-incident exercise was held in October 2015, and 11 companies (1 parent company and 10 subsidiaries), 103 people participated. The exercise scenarios were the following two-incident response activities. (The scenarios were not informed to participants in advance.)

Scenario 1:
- Serious software vulnerability information (threat information) is conveyed from the parent company to 10 subsidiaries. The parent company instructs the subsidiary to respond and report. (Teleconference and our system are used for communication.)

- Each subsidiary responds and reports to the parent company. (Our system is used for communication.)

Scenario 2:
- Information leakage from targeted attacks is discovered in one subsidiary. The subsidiary reports to the parent company. (Our system is used for communication.)
- Response method (application of pattern files of antivirus software, etc.) is indicated from the parent company to all subsidiaries. (Teleconference and our system are used for communication.)
- All subsidiaries respond and report to the parent company. (Our system is used for communication.)

4.1 Quantitative evaluation by log analysis

Sharing information with other companies is not common regarding cyber-incident response. However, a subsidiary needs to report its situation to the parent company. Figure 9 shows the flow of information. Company A is a parent company of subsidiaries B to K. Three departments of Company A participated in the exercise. Department A-1 participated in the same position as other companies, department A-2 provides technical consultation on cyber security, and department A-3 manages the subsidiaries. Three flows of communication, i.e., communication within each company, inquiries to department A-2, and report to department A-3, are also shown in Fig. 9.

From \ To	A-1	B	C	D	E	F	G	H	I	J	K	A-2	A-3	ALL	Cont roller	Total	%
A−1	5												5	2	1	13	4%
B	1	19										2	5	0	5	32	9%
C			16									4	5	0	15	40	11%
D												2	1	0	24	27	8%
E					18								5	0	13	36	10%
F						3						3	8	0	8	22	6%
G							11							0	5	16	5%
H								4					4	0	32	40	11%
I													3	0	11	14	4%
J										1			4	0	6	11	3%
K											6			0	3	9	3%
A−2						1						1		8	4	14	4%
A−3	1	1	1		1						1	1		10	9	25	7%
Controller	2	6	6	5	6	7	3	3	4	3	3	7		0		55	16%
Total	9	26	23	5	25	11	14	7	4	4	10	20	40	20	136	354	100%
%	3%	7%	6%	1%	7%	3%	4%	2%	1%	1%	3%	6%	11%	6%	38%	100%	−

Fig. 9 Overview of message flows

The change in the number of messages per scenario over time is shown in Fig.10. In scenario 1, communication between organizations is instantly made with the sharing of threat information as a trigger, and it declined as time passed, indicating that prompt action was taken. In scenario 2, since the incident occurred at different times for each company, communication was distributed as a whole.

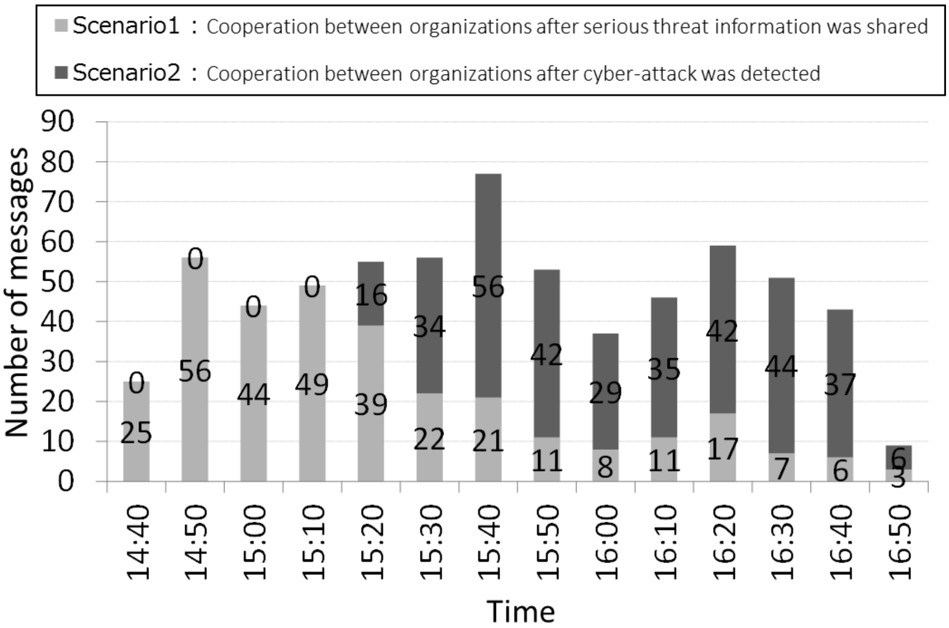


Fig.10 Transition in number of messages

4.2 EVALUATION BY QUESTIONNAIRE

The number of respondents to the questionnaire was 57 for Q1_1, 32 for Q1_2 (42 answers), 57 for Q2_1, 18 for Q2_2 (23 answers), 43 for Q3_1 (44 answers), and 49 for Q 3 _ 2 (94 answers).

4.2.1 [Q1_1] EFFECTIVENESS OF COMMUNICATION BY FREE-FORMAT DESCRIPTION

Free-format description was verified as being “useful” by more than half the respondents, as shown in Fig. 11. Since persons in charge of the cyber-incident response were accustomed to handling incidents using e-mail, the rate of "ordinary" was over 20%.

4.2.2 [Q1_2] COMMENTS ON COMMUNICATION BY FREE-FORMAT DESCRIPTION

There were comments such as "It takes time to understand the contents because the message is too long" and "When new messages come in succession, the location of the message on the screen changed at the time of updating the screen so it was hard to read it".

4.2.3 [Q2_1] VALIDITY OF "THREAT INFORMATION/SITUATION VIEW" SCREEN

Less than half the respondents stated that the "threat information/situation view" screen was "useful", as shown in Fig. 11. Similar to Q1_1, the rate of "ordinary" was more than 25%.

4.2.4 [Q 2_2] COMMENTS ABOUT "THREAT INFORMATION/ SITUATION VIEW" SCREEN

By providing "threat information" and "situation view" separately on the Do screen, there was an opinion that, "It was easy to understand threat information" and "It would be convenient if there were a link with the related messages on the communication board on Do screen". We found that it would be better to display atypical information on a different board according to the purpose such as "communication" or "information sharing".

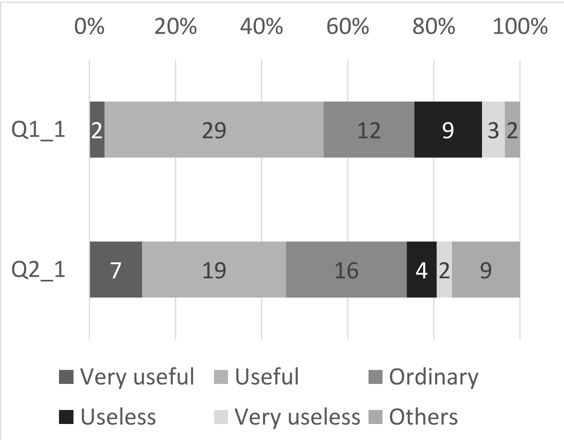


Fig. 11 Results of Q1_1 and Q2_1

4.2.5 [Q 3_1] WHAT IS GOOD ABOUT THE SYSTEM?

We classified this question from four viewpoints, "display", "function", "system operation", and "procedure" (Fig. 12). There were many comments on function. Regarding the viewpoint of display, there was a comment that, "The communication of one topic is displayed in a batch, so the status of each company could be easily grasped". The following comments are regarding the viewpoint of function, "It is convenient to be able to see the information from each organization", "It is easy to share information", "It is easy to exchange information among organizations", and "It is good to be able to store activity logs." Regarding the viewpoint of system operation, there was a comment about how operation was simple and intuitive. Regarding the viewpoint of procedure, the importance of centralizing information to a dedicated tool was mentioned.

4.2.6 [Q 3_2] WHAT IS BAD ABOUT THE SYSTEM?

We classified this question from the same viewpoints as in the previous question (Fig. 12). There were many opinions on the viewpoint of display. There was a problem of "losing sight of the message being read when updating the screen if the messages come in succession". Also, there were requests such as "I want to sort messages by time order" and "I want to distinguish between unread and read". It was also found that it was difficult to read a long message, so it is also necessary to improve the screen layout according to the size and resolution of the display. From the function viewpoint, there was a demand for flexible searching and sorting functions. There were also requests for customization functions such as multiple tags and colors on each message. From the viewpoint of system operation, there was an opinion that, "Since we usually use e-mail, it would be convenient to be able to do the same operation as e-mail". From the viewpoint of procedure, there was an opinion that, "In order to cope with multiple incidents simultaneously, it is necessary to further organize the method of communication." Also, there were the following opinions; "I was wondering whether to make a new message or reply to an existing message when making a message" and "It is better to limit the people who enter messages into the system to avoid confusion."

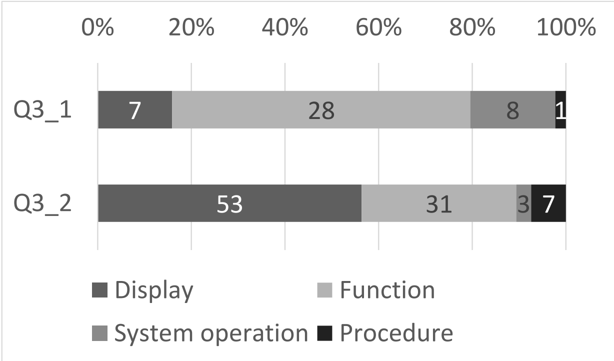


Fig. 12 Results of Q3_1 and Q3_2

5. COLLECTION OF COMMENTS THROUGH INTERVIEW

At a later date, we asked members of the cyber-incident response teams from the largest six companies who had participated in the exercise to use the system with some GUI improvements. We interviewed them regarding the Do, Plan, and See screens (the Plan and See screens were not used in the exercise). We explain the interview results below.

5.1 STATISTICAL ANALYSIS OF COMMENTS

We classified comments from each company's staff members in the interview in terms of the viewpoints of "function", "operational knowledge", and "work efficiency improvement ", as shown in Fig.13. Since the interviews were conducted while they were using the system, there were many comments on function.

Viewpoint	a corp.	b corp.	c corp.	d corp.	e corp.	f corp.	Total
1.Function	151	199	60	141	260	166	977
2.Operational knowledge	17	50	56	35	4	1	163
3.Work efficiency improvement	10	0	1	0	0	0	11
Total	178	249	117	176	264	167	1151

Fig.13 Classification of all comments

Furthermore, comments on function can be classified as "Plan screen", "Do screen", "See screen", and "Other functions", and the results are shown in Fig.14. There were many comments on the "Do screen", which is the core of the communication-support function.

	a corp.	b corp.	c corp.	d corp.	e corp.	f corp.	Total
1.Plan Screen	50	69	15	46	28	57	265
2.DoScreen	64	43	19	75	183	58	442
3.SeeScreen	1	26	5	0	15	19	66
4.Other functions	36	61	21	20	34	32	204
Total	151	199	60	141	260	166	977

Fig.14 Classification of comments on function viewpoint

We classified the above operational-knowledge viewpoint into the four elements of "governance", "standard operating procedures", "training and exercises", and "usage", as shown in Fig. 15. These four elements are a subset of the five elements of the Interoperability Continuum [11] formulated by DHS. For the introduction and use of communication tools, "governance" and "standard operating procedures" are important, so there were many comments related to these two elements.

	a corp.	b corp.	c corp.	d corp.	e corp.	f corp.	Total
1.Governance	7	36	16	8	0	0	67
2.Standard operating procedures	9	10	37	16	2	0	74
3.Training and exercises	1	2	0	3	0	0	6
4.Usage	0	2	3	8	2	1	16
Total	17	50	56	35	4	1	163

Fig.15 Classification of comments on “operational knowledge viewpoint”

In the next chapter, we describe the opinion on the "function viewpoint” for each Plan, Do and See screen.

5.2 COMMENTS ON FUNCTION VIEWPOINT

5.2.1 PLAN SCREEN

There was an opinion regarding the Plan screen that “The composition of the Operational Planning “P” may change depending on the type and scale of the incident”. Cyber incidents vary in their type and scale. Regarding natural disasters, the “P” is formulated for large incidents against which multiple organizations cooperate. To apply the “P” to cyber incidents, multiple types of “P” according to the scale and kind may be needed.

There was also an opinion that, “The sequences of the steps that make up the “P” may change depending on the situation.” A cyber incident has different properties from a natural disaster such as “There is a malicious person behind an incident”, “There are cases in which it is hard to notice the incident occurring”, and “There are cases in which the cause of the incident is not immediately understood”. Therefore, it is necessary to be more flexible in responding to cyber incidents.

There was an opinion that, “When dealing with incidents in cooperation with other organizations, it would be easy to cooperate if the progress status of other organizations could be known from the “P” checklist.” Regarding cyber incidents, it is not easy to notice the damage and response situations, so there were such opinions. However, there was an opinion that, “I do not want my organization's progress to be known to other organizations.” People do not want other organizations to know about, for example, the slowness of their organizations’ responses.

In addition, there was an opinion that it would be convenient to automatically send e-mail requesting conference participation to participants and automatically start a conference system according to the conference schedule registered on the Plan screen. By linking between different communication tools, convenience can be improved.

5.2.2 DO SCREEN

There was an opinion regarding the Do screen that, "The function of setting the disclosure range of the message is essential". With cyber-incident response, control of the scope of disclosure is considered indispensable because there are cases in which sensitive information, such as internal information, of an organization is handled.

There was also an opinion that, "It would be convenient if it were possible to enable/disable 'copy message' and 'download attached file'". To reduce the possibility of leakage of sensitive information, such a function is considered effective. Also, there was an opinion that, "It is possible to put the information acquired by telephone or e-mail into the Do screen to share it between organizations." Because there are advantages/disadvantages to each communication tool, it is necessary to use them properly at the right place. Moreover, there was an opinion that, "It is hard to understand who should change the 'status' of each message or task at which time." To avoid confusion when handling incidents, it is necessary to decide how to use communication tools and share this information among organizations in advance.

5.2.3 SEE SCREEN

There was an opinion regarding the See screen that, "It is convenient to use it to aggregate information of statuses from many organizations when dealing with software vulnerability". We received the same opinions during a drill of natural-disaster response. However, there was an opinion that, "We do not want to show our situation to other organizations other than the parent organization." It seems that such opinions come from the feeling that they do not want criticism from other organizations.

There was also an opinion that, "The information to be consolidated is different depending on the type of incident". Even in natural disasters, the information to be summarized varies depending on the type of disaster. It would be useful to prepare several templates for information input in advance, and it would be convenient if there were a function to edit input items flexibly when an incident occurs.

6. CONCLUSION

Through a cyber-incident exercise, we verified the effectiveness of our integrated risk-management support system for cyber incidents. From this exercise, mainly regarding the Do screen, the opinion that, "the system is useful" was stated by about half the respondents to the questionnaire, and negative opinions were stated by about a quarter of the respondents. During the exercise, a telephone conference was held during which the situation of each company was shared and future policy was decided. Each company wrote a chronology of the incident-response activities and to-do list on a white board. These activities can be supported with the Plan screen. The parent company summarized the damage situation of each of its subsidiaries on a white board and tried to obtain an overview of the situation. These activities can be supported with the See screen. Therefore, we found that our system can be applied to cyber incident response activities and improve resilience in cyber field.

In the interviews with the six companies after the exercise, we were able to understand how to modify our system when applying it to cyber incidents. We believe that it is necessary to improve readability for users to understand messages or the situation at a glance while handling atypical information. We also believe that it is necessary to develop a "standard operations procedure" on how to use the system in certain situations.

7. ACKNOWLEDGMENTS

In promoting this research, we received valuable cooperation from the staff who participated in the exercise and interviews. We express our deep appreciation to them.

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Resilience Information Portal

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ABSTRACT

The Smart Mature Resilience Project is a European research Project aimed at developing a Resilience Management Guideline. The guideline is composed of five tools developed in the project. They help to determine the level of resilience of a city and how to improve it.

The Resilience Information Portal, one of these five tools, must support and integrate the different tools. It is also used as an engagement and communication tool.

The tool had to be built before the finalization of the requirements, so a double approach was pursued in this project. First, a fast prototype was built based on a CMS, and second, a solution was built from scratch. The paper explains this process, compare both approaches, and how the long way can be more efficient. The final version has shown to be easy to use, and powerful enough to respond to the requirements of the users of the portal.

Keywords

Resilience, portal, information system, CMS, software development.

INTRODUCTION, THE SMART MATURE RESILIENCE PROJECT

The Resilience Information Portal presented in this paper is part of the Smart Mature Resilience Project (SMR). The SMR is a European research project funded by Horizon 2020, the largest research and innovation program in Europe, available from 2014 to 2020. The project is one of the 5 projects funded under Crisis management topic 7: “Crises and disaster resilience - operationalizing resilience concepts”. The projects in this topic should provide “the development of European Resilience Management Guideline and demonstration through pilot implementation.”

The SMR project addresses the objective of developing a Resilience Management Guideline with three pilot projects in the sectors of Critical Infrastructure security, climate change and social dynamics. The guideline will be supported by a set of five tools that will be developed in the project by the different partners. The guideline will increase the resilience of the cities. The concept of city resilience emphasizes the capacity of the city stakeholders to adapt not only to the shocks such as earthquakes, fires, and floods (Bruneau et al., 2003; O’Rourke, 2007; Fisher and Norman, 2010; Bakkensen et al., 2016) but also to the stresses that affect a city on a day-to-day basis such as climate change. By addressing both the shocks and the stresses, a city becomes able to respond to adverse events, and is overall better equipped to deliver basic functions in both good times and bad, to all populations (Spaans and Waterhoutd, 2016).

The project focuses on cities because nowadays, the majority of the world’s population live in cities and, according to projections, this number will increase over the coming decades (100 Resilient Cities, 2016). Accelerated globalization has dramatically increased the complexity and unpredictability of threats and hazards that affect cities (Bach et al 2010). As cities continue to grow, they face an increasing variety of challenges ranging from short-term shocks such as floods, droughts, and earthquakes, to long-term stresses such as climate change (Prior and Roth, 2013).

Partners

The partners of the project are 7 cities, 4 Universities and 2 other organizations. The importance of the cities in this project is represented in the number of cities in the consortium. The cities are 1) Kristiansand (Norway), 2) Donostia/San Sebastian (Spain), 3) Glasgow (Scotland), 4) Vejle (Demark), 5) Bristol (England), 6) Roma (Italy) and 7) Riga (Latvia).

Some of the cities belonged already to other resilient networks, so they have experience with the goal of the project and others are the city of one of the universities of the project that helps to implement the different tools.

The universities are: 1) TECNUN the School of Engineering of San Sebastian, of the University of Navarra, and leader of the project, 2) The Centre for Integrated Emergency Management (CIEM) of the University of Adger, 3) the University of Strathclyde in Scotlandand 4) Linköping University in Sweden.

The two other organizations are 1) ICLEI with a wide experience supporting local and regional governments in sustainable development, and 2) DIN, the German institute for Standardization, because one of the goals of the project is establish the Guideline as a standard.

Five Tools

The five tools (figure 1) that will form the Resilience Management Guideline are the following:

1) The Resilience Maturity Model is the foundation for the guideline. It defines the current resilience stage of a city ant the path to go to the next level. These levels are: Starting, Moderate, Advanced, Robust, verTebrate. Its initials are the word SMART. Each stage has five dimensions: robustness, infrastructures and resources, cooperation, learning, preparation, and leadership and governance. The model defines policies for each stage and dimension. The description of the levels are:

> Starting: the crisis management is based on risk assessment without having an integrated approach towards multi-hazard approach.
>
> Moderate: The risk assessment with regard to hazards affecting Critical Infrastructures is operationalized in cooperation with Critical Infrastructure providers in order to deliver essential services in case of crisis.
>
> Advanced: The city has developed an operational resilience action plan with holistic approach that integrates all sectors and relevant stakeholders.
>
> Robust: All relevant stakeholders to be involved in the resilience action plan have been identified and engaged the majority of them.
>
> Vertebrate: The city excels regarding its resilience as part of the regional, national and global system resilience, understanding that in order to become resilient the environment needs to be resilient as well. The city acts as a vertebra in the European resilience backbone.

2) The System Risk Assessment Questionnaire that helps identify the risk of a city and to determine the maturity level of the city.

3) The portfolio of Resilience Building Policies that defines the path to the next maturity level.

4) The System Dynamics Model, build based on the Resilience Maturity Model, that allows the government of the city to play with different policies and observe the result of the decisions in the different variables that defines the resilience of their city.

5) The Resilience Information Portal that is described in this paper.

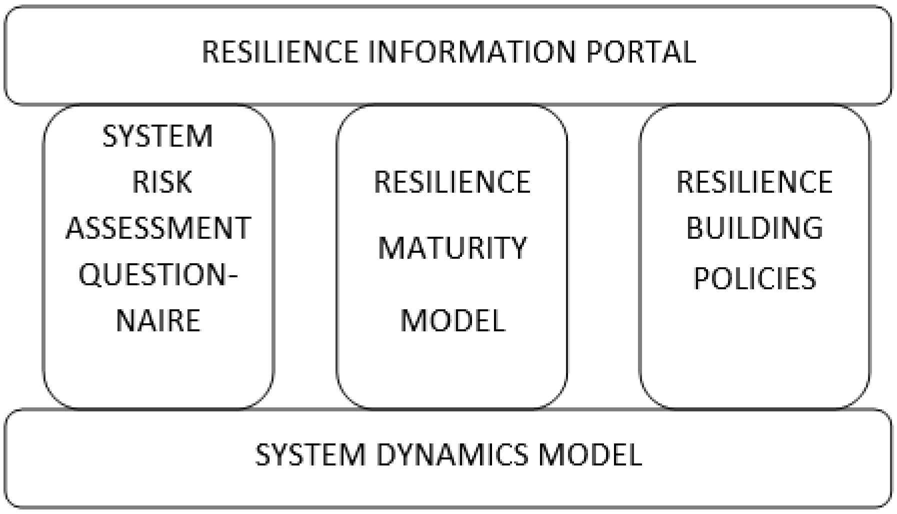

Figure 1. The 5 tools of the Resilience Management Guideline

THE RESILIENCE INFORMATION PORTAL TOOL

The Resilience Information Portal aims to facilitate different levels of communication and engagement in resilience building activities. It describes the information system that is actually developed as a prototype for the project and that cities will implement. The Resilience Information Portal deals with a technological aspect of a communication tool for cities and stakeholders while cities also need to develop relevant processes and the required ecosystem as a non-technological perspective. The Resilience Information Portal is used in the project to align it terminologically with the other tools that are currently developed. The portal is supposed to be used to respond both short-term and long-term shocks and stresses that cities are facing. For instance, cities have to manage a disaster situation as a short-term shock. Responding actual incident requires a city's resilience in order to avoid harm and to mitigate negative consequences while a medium- to long-term development does not require immediate action. Likewise a refugee crisis, cities need to set up an efficient communication environment with citizens and stakeholders. As an example, cities could use the portal to keep the public updated with news on arriving refugees respectively the virus spread and how refugees are distributed to shelters. In this case the portal also serves as providing a backchannel where citizens can comment on the situation of the event as well as on consequences for themselves. The portal has several sets of functional requirements. For instance, the portal should employ social media integration, search functionality and data management and so on.

The portal is proposed as a toolbox with rather coarse, yet very versatile functionality that allows cities to try out ideas, share best practices, use the portal as a showcase, and to adapt successful practices to their own portals. After the project, the portal will be used as the Resilience Information Portal of each city.

STANDARD TOOL OR CUSTOM TOOL

The Resilience Information Portal has two delivery dates in the project. The first one six months after the start and the second one 18 months after the start, in the middle of the three-year project.

First version

The first version of the portal had to be working six months after the start of the project. This time included the development of the first version of the requirements. Therefore, the time available to produce a version that the users could test weeks before the deadline was reduced. Due to this limitation, this first version was designed with a CMS (Content Management System). The CMS chosen was Typo3 because it is the same CMS used to develop the project web site (http://smr-project.eu). So, the tool was developed with the same CMS that hosts the web site. This makes it possible to maintain the same style and produce templates for the Resilience Information Portal more easily.

This version is available at http://portal.smr-project.eu. There are different templates for use by the cities and partners in the project, or by other users who want to improve their resilience stage. The goal of this first version was to test the functionality of the tool by the cities."

Figures 2 and 3 shows images of this first version. The home page (figure 2) shows the main news of the project, and a navigation menu to access the different sections of the portal. The City of Donostia page (figure 3) presents an example of information that the city can share with the tool, including subpages for citizens and stakeholders.

Figure 2. Home of the first version of the portal

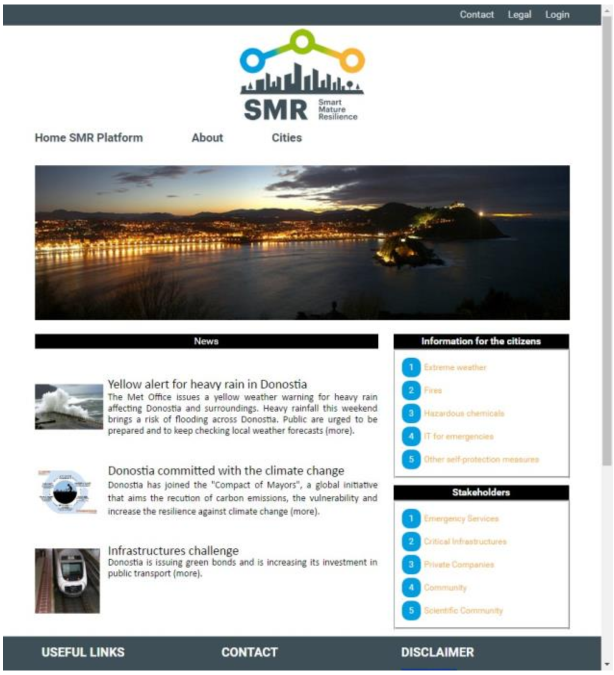

Figure 3. City page with the first version of the portal

Requirements

Together with the first version of the portal, the deliverable 4.1 of the project was delivered. This is the document that explains the process and results of defining the principles and requirements of the tool. The title of this document is “A communication platform that facilitates different levels of communication and engagement as a shared resource in the project,” available online at the project web site (http://smr-project.eu/fileadmin/user_upload/Documents/Resources/WP_4/D4.1_Communication_platform.pdf) (Grimes et al., 2017).

The result of this document is an initial set of requirements. It includes a definition of the product:

"The aim is to build a Resilience Information Portal. It will serve as a collaborative environment to facilitate awareness and engagement among key partners in resilience building activities. The portal aims to offer knowledge sharing and facilitate collective learning.”

And some “Must” and “May” criteria. We include them here to understand the scope of the tool:

Must Criteria

• The portal must be a publicly available Web application.

• The portal must provide functionality to embed static content as well as dynamic content. In particular, it must be possible to have Newsfeeds, Weblogs, Wiki pages, and Forums.

• Users must be able to register themselves for portal usage and log in.

• Logged in users must be able to customize pages that are set to be customizable. In particular, the home page should be customizable.

• An adaptive role management must be realized.

• Logged in users with respective rights must be able to edit pages. This includes the upload of documents.

• Administrators or users with rights for sub-areas of the portal must be able to generate new pages as well as to remove pages from the portal.

• Page editing must be supported by WYSIWYG tools (i.e. easy editing tools that do not require programming or design knowledge).

• Accessibility standards as outlined by W3C must be followed.

• A search functionality must be provided that allows to sort information.

May Criteria

• The portal may support multiple languages.

• Mobile device support ought to be pursued.

• Accompanying Wiki pages, Frequently Asked Questions (FAQ) pages could be provided

• Tools for interactively measuring the resilience maturity level of a city could be provided.

With these requirements, we had to choose the way to develop the final version.

Second version

For the final version, we selected a different approach due to the fact that the final requirements are going to be more demanding and although the CMS used allows a rapid prototype, it is probably going to be difficult to adapt to fulfill all the principles and requirements specified for the portal. This is the reason to start the development of the final version from scratch, taking into account the experience, design and content developed in the first version.

The pros and cons were weighed when making the decision of whether to continue with the CMS used in the first version or develop it from scratch. An “off-the-shelf” tool like the CMS used has the advantage of many features already tested and ready to be used, but it also means that the software must be used as it was designed, allowing only customizations supported by the designers of the CMS. In the case of Typo3, it can be argued that since it is an Open Source CMS, all the source code is available for customization, but due to the size of the work package and the size of the Typo3 project, this was not a feasible solution.

Examining the principles and requirements of the portal, we analyzed that the amount of core functions that were going to be used from the standard tool was quite low compared to the specific requirements of the

Resilience Information Portal. Although starting from scratch implied some initial development of standard features, in a few weeks the prototype provided the same functionalities as the previous one, and the inclusion of new functionalities was easier due to the total control over the existing code.

Also, we must clarify that the expression "from scratch" must be considered in the scope of the project developed. The portal is a web application and most web applications are developed with technologies that provide solutions for most of the challenges affecting applications of this type. The next section explains the technologies selected for the development of the portal.

Technologies

The first requirement of the portal is to be a web application: "The portal must be a publicly available Web application." Requirement A01 of deliverable 4.2 (http://smr-project.eu/papers/#c3650).

It may seem obvious, since most of the current applications developed nowadays are web applications, but in this case, it is a written requirement. And this requirement defines the architecture of the application: a web application has a server side and a client side. On the client side, the HTML, CSS and JavaScript render the user interface for the final user showing the information requested and allowing that the user enter or update the information with the provided user interface. On the server side, the application programs manage this information, which is stored in a database on the server. In this case, it is necessary to decide which platform to use.

The deliverable 4.2 specifies that: "It should be a fully cloud-based information system." A web application can be hosted on the cloud in three different ways: SaaS, PaaS and IaaS (Serrano et al., 2015). Typo3 is a SaaS (Software as a Service), which is the easiest to implement but not so easy to customize as we have discussed in the previous section. The choice is whether to use a PaaS (Platform as a Service) or an IaaS (Infrastructure as a Service). In this case a PaaS was chosen because there is no need for a SQL Database and it allows the automatic scaling of the platform without any specific management. The platform and language chosen was App Engine with Java due to experience in previous projects and because they are widely used.

App Engine

Using a PaaS (Platform as a Service) is the most convenient way to develop a custom web application to prevent the overload of managing servers, load balancing, clusters, security packages and all the administrative tasks involved in maintaining a farm of servers. One of the most popular PaaS is Google App Engine, which we have selected for this prototype. App Engine allows to use different programming languages; for this project we selected Java, a well-known language for developing enterprise applications.

Servlets

The basic element for developing web applications with Java is the servlet. The servlet is an application, written in Java, that runs on the server based on requests from the client side, processes the request, reading and storing, if needed, any incoming input, and produces a response that is send to the client to be rendered in the browser of the final user. Our portal will consist of a set of servlets that can produce all of the elements the end user needs to manage the portal and produce the final web pages, which is the ultimate goal of the Resilience Information Portal.

Entities

While the above definition of the behavior of the application is complete, it is quite concise and therefore it is easy to confuse the elements for managing the portal with the final web pages themselves. The reason is that in a web application all the elements are web pages; see the pages shown in figure 4 for an example. But web pages are also the final goal of the Resilience Information Portal: the web pages that the city stakeholders are going to use to share information and engage the public use of the portal. To create these web pages, the users are going to use other web pages, the web pages in the application, to create their final web pages and the other elements needed to manage the portal, i.e.: users, organizations, data sets and the information and security of the web pages. These elements are known as "entities," the name used in this paper.

For example, the entity "user." To manage a user in the application, we must know the person's username, password, email and name of organization. The final user edits this information with the application, as shown in figure 4.

Figure 4. Page to edit a user

To manage a user, fields (username, password, email, organization) are stored on the server and can be managed by the administrator of the application with a servlet that can perform different operations; for example: a) show the user information of the different users in a list, b) show the information of user allowing the field values to be modified and sending this information to the server, c) read the information modified by the administrator and store it on the server, etc. These operations can be performed by one or several servlets. In the portal architecture we have decided that one servlet will perform all the operations related to a specified entity. In this case, the “Users_Action” servlet performs all user-related operations.

Now that the concept of entity is clear with the example of a “user,” we will see how the entity “UserPage” (pages generated by the user) is managed with the application. The same way we create or modify a user, we can create or modify “UserPages”. In this case, the servlet that is going to perform these operations is the “UserPage_Action” servlet. You can follow their activities in the browser URL when you create or edit user pages.

When you create or edit a user page, one of the fields on the user page is the content of the web page. In the application, it is edited with an online web editor. See Figure 5.

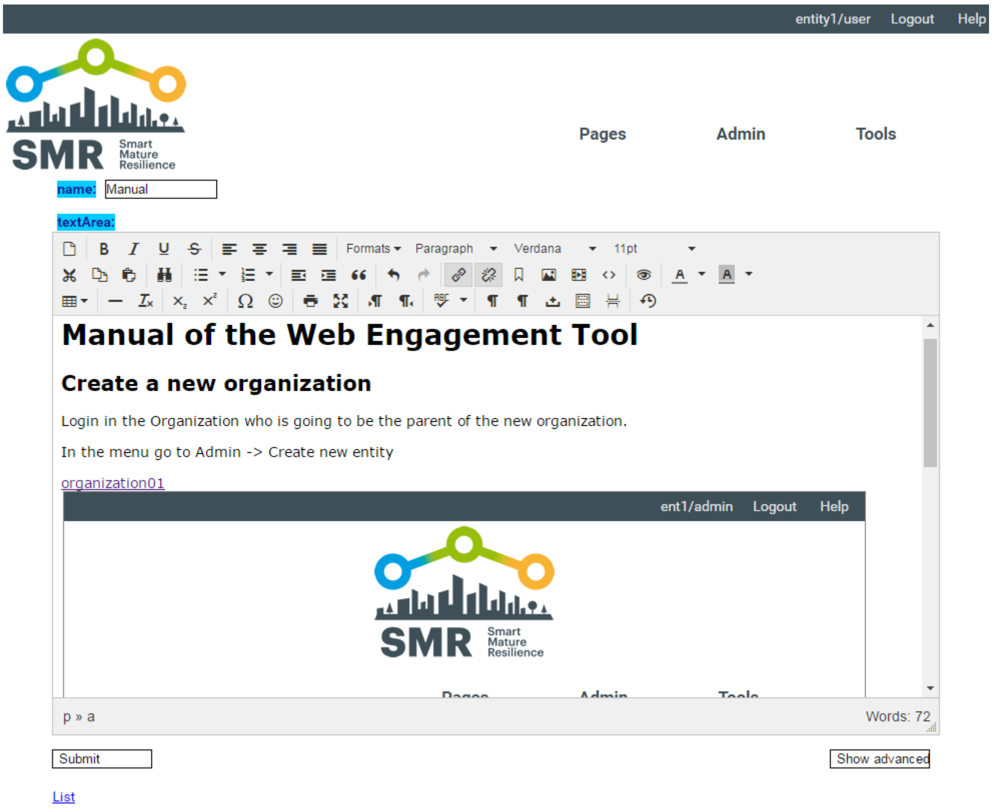

Figure 5. Page to edit a User Page

Although the field for editing the content of the web page is more complex than the field for editing the name, internally they are stored very similarly on the server.

In this case of the "UserPages" we have an additional servlet that renders the final page. For example, to render the manual of the application we use the servlet UserPage with the url: http://smr-project-test.appspot.com/UserPage?PageKey=5193646789885952 This servlet reads the information on the web page and produces the output of the final page for other users of the application.

Data structures

One of the requirements that led to deciding to build from scratch was "The portal must provide the functionality to provide existing dynamic content". (Requirement A05).

As explained in the previous section, the application needs to manage information of different entities (users, organizations, pages, etc.). But this requirement states that it must provide dynamic content. Traditionally, the information provided by an application is organized in tables or objects in a database, like the entities of the portal. These tables are defined with the design of the application and each one has its own application (servlets in our case) to manage them. However, this requirement talks about dynamic content, that is, content that was not predicted in design time. This adds great flexibility to the use of the portal because it can include elements that were not predicted when the tool was being built. But it also involves a challenge to provide this functionality.

To address this question, the portal uses the concept of data structure. A data structure is a type of content, organized similarly to the information in a table. It can have different records and each record has a set of fields. The portal must be able to define and use these data structures.

The Data Structure entity

To define a data structure, the portal uses the concept of Data Structure entity. A Data Structure is defined by a name and a set of fields. We are going to see it with one of the required criterion for data structures: a contact list (A04). The name of this data structure is "contacts" and the fields or items of a record are: name, phone, email, address, skype. The portal uses two servlets to manage these elements: RegisterType_Action and

RegisterTypeItem_Action. With these servlets the final user is able to define new Data Structures and their items. An item is composed of a name, the order of this item in the set of items and the type item (string, number, date, etc.). The user can also modify an existing Data Structure, changing its name, or the different items of the Data Structure.

When the Data Structure is defined, the user or other users with the defined permission can insert and see the content of the Data Structure.

Using a Data Structure

The users can define different data structures with very different purposes; one, for example, to be used as an address directory and another to register levels of floods. However, all of them are managed by the portal in the same way: each entry is a record of the defined data structure that is stored on the server.

The user can therefore interact with a defined data structure to see the content, add a new record, or modify an existing record. The application could provide different forms for these operations, but instead, a more flexible approach was chosen to allow the integration of external data as described in requirement A05. For this purpose, the application uses a JSON format to provide the data. Very briefly, JSON (JavaScript Object Notation) is a lightweight human-readable data-interchange format. That means that it is very easy to use on the server and especially on the client, where JavaScript is the language to manage web pages.

The client in the browser can read the JSON data and format it however the application requires. The example in Figure 6 shows a standard table.

View	id	order	name	phone	email	adress	skype
view	4860816083910656	3	Municipal Guard	092	udaltzaingoa@donostia.org	Calle Easo, 41 20015 Donostia, Gipuzkoa	MunicipalGuard
view	4865814888972288	4	Hospital	943007000	hdo.sapuar@osakidetza.net	Begiristain Doktorea Pasealekua,117, 20015 Donostia, Gipuzkoa	Hospital

New register

Figure 6. Data from JSON in table format

To create a new record, the application generates a form with the structure of the data structure (figure 7), and for editing an existing record, it creates the same form but populated with the values of the fields (figure 8).

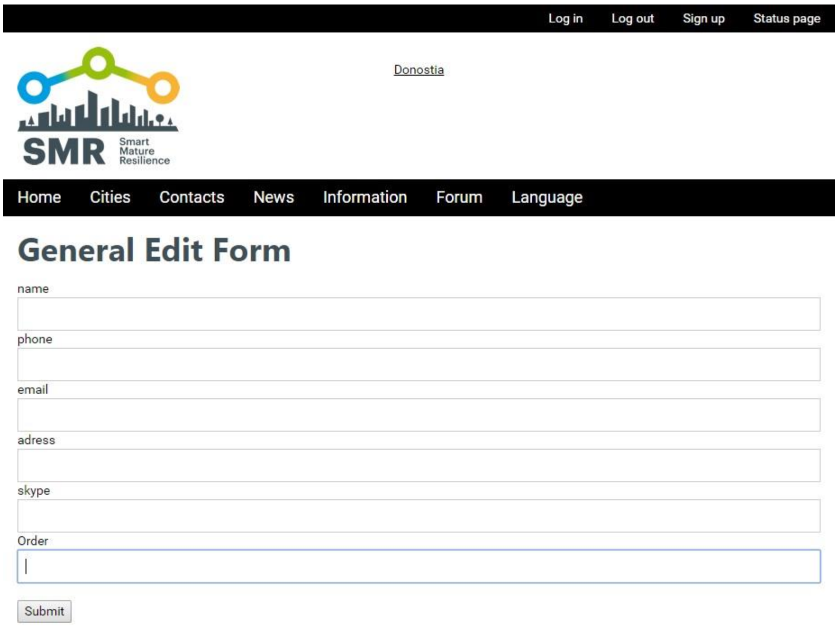

Figure 7. Form to create a new contact register

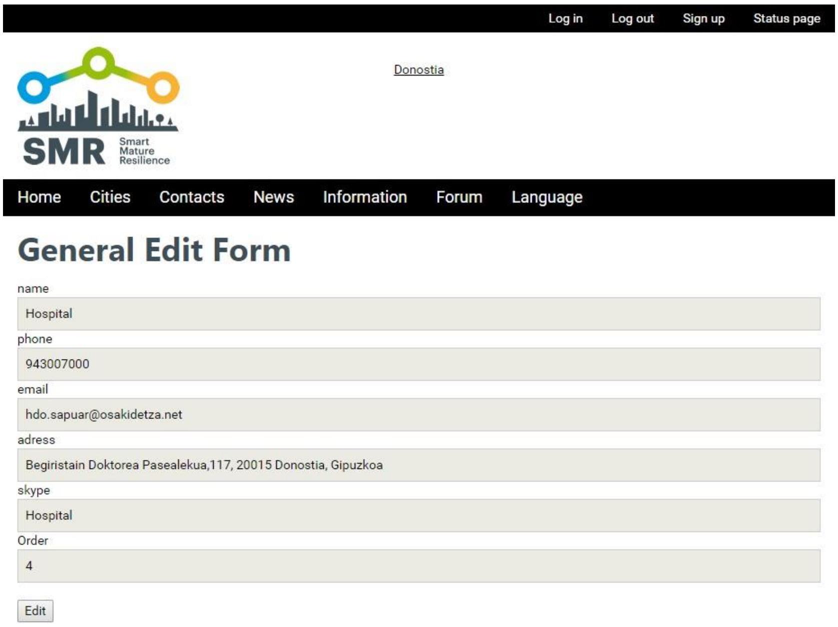

Figure 8. Form to edit an existing contact

With this architecture, the final user can edit web pages in which the data can be used in different ways. For example, the web page of a city (figure 9) uses the News data structure, the Warnings data structure and the Contact data. A user can record this type of information with forms similar to the forms shown in figure 7 and figure 8. The web page of the city integrates these data.

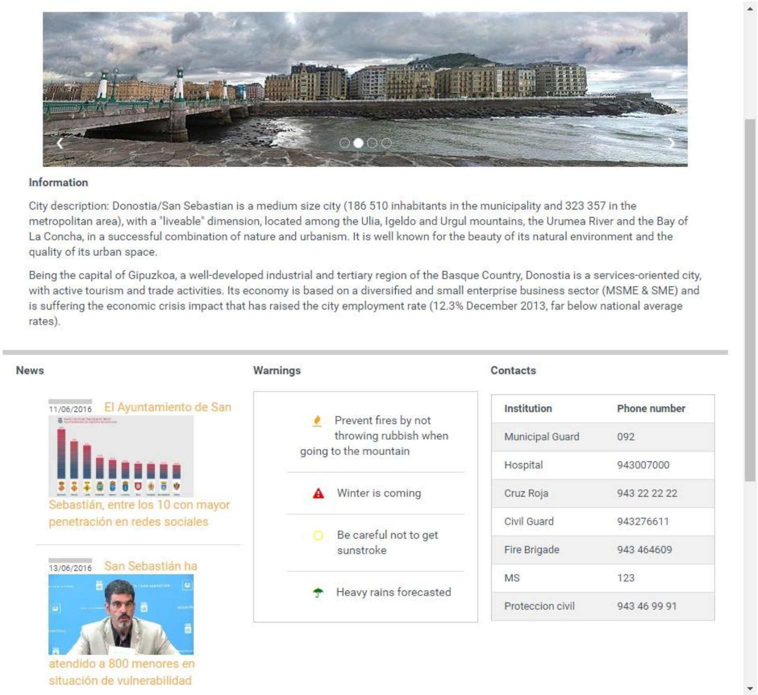

Figure 9. Page with data to show news, warnings and contacts

Another example of using the data structure is to show the different values of the records of the data structure in a graph. In figure 10 you can see how the editor of the page has used a graphics library to show graphically the values of the records, without modifying the portal code.

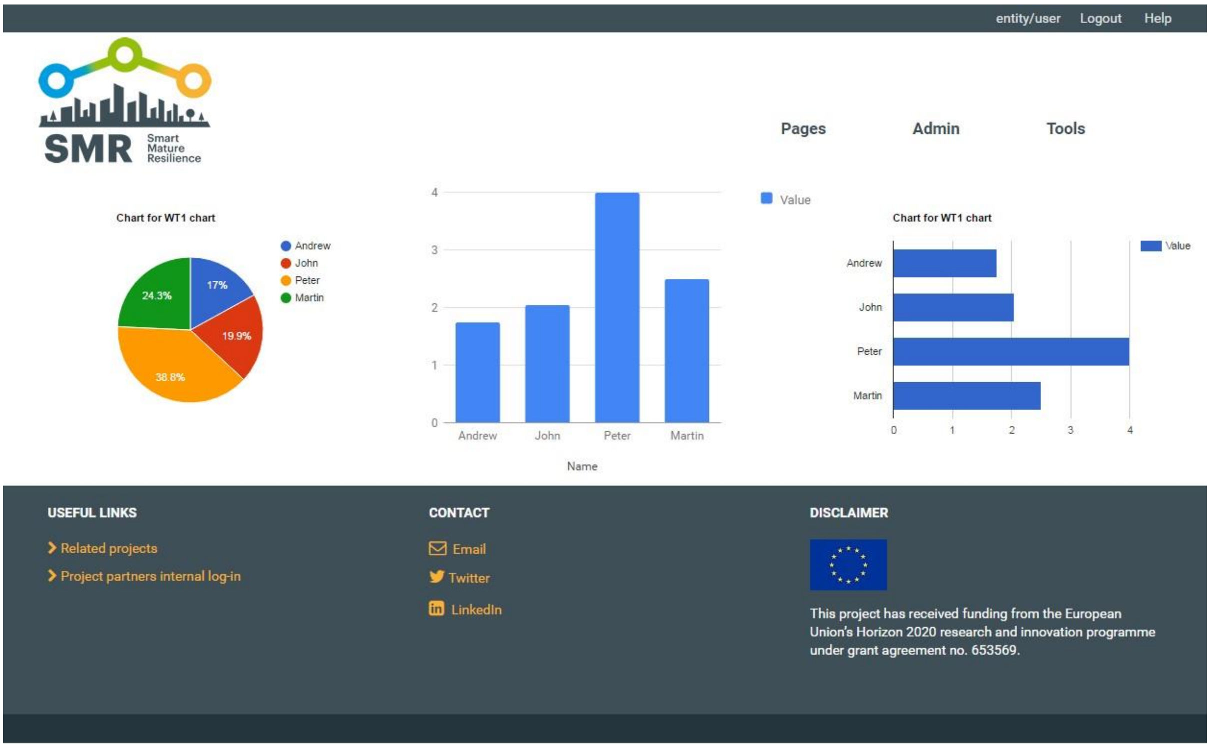

Figure 10. Chart with values from a data strcutre

The protocol to interact with the server to read or write the values of the records of the different data structures is quite simple as can be seen in the different examples of the portal.

The JSON values obtained from the request can be used on the application in different ways, as we have explained in this section (tables, forms, graphs, custom templates) and can be read with different tools (plain JavaScript, as in the example of the table, or with JavaScript frameworks as AppML or Angular JS).

USES OF THE RESILIENCE INFORMATION PORTAL

The tool presented in this paper is the Resilience Information Portal of the SMR project. Therefore, it will be used as the collaborative and engagement tool between projects partners and in the cities to improve communication between cities, citizens and stakeholders.

In the project there is a work package (WP5) that integrates the different tools of the project. The portal is one of the tools; it is, indeed, the tool that allows the integration of all the tools, so the use of the portal is basic for the fulfillment of the goals of the project.

The portal has been used in different workshops, first to understand its functionality, because although it is quite basic, a user does not use a new tool without the appropriate support. For this purpose, the portal has several tools to facilitate use of the portal. Here are some of these tools:

- Status page (http://smr-project-test.appspot.com/status.page). Explains the basics concepts of the portal.
- Tutorial (http://smr-project-test.appspot.com/tutorial.page). Explains, step by step, the main functionalities of the portal.
- Video tutorial (http://smr-project-test.appspot.com/videotutorial.page). Explains the main functionalities of the portal with videos.

http://smr-project-test.appspot.com/tutorial.page

There are specific workshops to practice using the portal with guided instructions. With this support the cities will be able to use the portal to collaborate with the different stakeholders and citizens. To manage this collaboration, the city can create a hierarchy structure with the complexity and depth needed for each specific city. The different nodes of this hierarchy can create new nodes if the parent node has allowed permission. Hence, the structure can accommodate the needs of every city and department or stakeholder.

The tools have a list of predefined templates that can be used directly from the cities or can be used as models to create custom templates for different purposes, departments, citizen organizations, stockholders or entities.

Although a user can be trained to use all the roles on the portal, usually there will be a specialization based on the different skills. One or several users will be in charge of managing the different users and organizations, another will be responsible for defining new templates and providing the basic support to be used by their organization, another will have the skills to create structures of data and integrate this information in different views on the portal, and so on.

Finally, the portal can be extended with new features, without the need to change its source code or making a new installation. The new features can be added with the inclusion of new pages for new purposes.

CONCLUSION

The portal created as part of the project has attained the goal of being an easy-to-use tool while meeting the requirements described in the deliverables.

It can be tested with the different examples presented in this paper and has been used as the platform to integrate the different tools of the project to achieve the goal of the project.

The portal has been shown to be able to support requirements arising after the development of the portal, as in the case of the System Dynamic model, another one of the project tools. The System Dynamic model was initially conceived as a model that needed to be integrated with the different tools. But when discussing how to develop it and based on the functionalities of the Resilience Information Portal, we started to build it directly on the portal. Therefore, there is no need to make a future integration and it is developed with an existing tool, making the learning curve easier for the authors.

The portal is a support tool for the project which has shown to be easy to use, and powerful enough to respond to the requirements of the different users of the portal.

ACKNOWLEDGMENTS

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement no. 653569.

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The Resilience and Its Dimensions

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ABSTRACT

Resilience has become a concept extensively used by several areas of knowledge. However, there is no method, widely recognized capable of measuring resilient behavior. Therefore, this exploratory work aims to present a set of dimensions capable of delimiting metrics in order to measure a resilient attitude. For that, we analyzed some scientific papers considered relevant by the academic community. In this work we follow an analytical flow seeking to conceptualize resilience and situate it in the context of complex systems. This analysis allowed the discovery of some characteristics regarding resilience, fundamental for the proposition of the presented dimensions. Finally, we present a conceptual map that brings together the elicited dimensions.

Keywords

Complexity, Complex Systems, Emergency, Resilience, Information integration, Information system, Systems integration.

INTRODUCTION

The chaos theory is a component of complexity theory and its main foundation is to seek for patterns in behavior of complex systems, so named for being able to respond disproportionately to any minimal change in one of its initial conditions. This fact shows both the non-linear character and the unpredictability present in these systems (McBride 2005).

This theory, mainly due to its transdisciplinarity, has been influencing the way in which the organizations are seen by the researchers, since these have similar characteristics to those observed in chaotic or complex systems. In this way, organizational phenomena, from a broad perspective, including the urban environment, have come to be understood in the light of this theory.

In order to ratify the complexity encapsulated in the concept of "organizations", it should be mentioned Maturana & Varela (1987), where an organization is detailed from a biology perspective and emphasizes the value of the relationships that make up as integral parts of certain real world objects. In fact, for an object to be known it is necessary to recognize the relations between its components, and this recognition process (implicit or explicit) beyond universal, constitutes a basic cognitive act based on the generation of classes of objects from the relations between its components, so that the object can be classified in a certain class. Therefore, it is relatively easy to point to a given organization by indicating the objects that make up a given class, but it can be complex and difficult to describe accurately and explicitly the relationships that make up the organization.

It should be noted that complex systems maintain a continuous and complex interaction not only with their environment, but also among their components. From this interaction emerge feedback actions capable to trigger mechanisms of self-organization as a way of ensuring the system to absorb not only the environmental impacts, but also their possible internal conflicts. Therefore, the capacity of self-organization occurs through the execution of a set of adaptive actions, which have close connection with the concept of resilience. Complementarily, the increasing complexity of social relations highlights the need to emphasize studies related to the interdependence between systems related to urban infrastructure. In this context, it is important to mention the importance of cooperation and information sharing between governmental and private sectors, since a significant part of critical infrastructure systems are in private hands (Pederson et al. 2006).

Resilience is a concept applied in several areas of knowledge, such as psychology, physics, mathematics, engineering, computing and others. It is understood generically as the ability of a body to return to its original form after suffering a certain concussion. Recently, this concept began to be applied in urban centers in order to contribute to the sustainability of the cities in the face of potential threats. In this regard two important concerns arises: the absence of uniformity in the definition of resilience and the lack of metrics to measure resilience in a given context.

This work presents an exploratory study aimed at enunciating dimensions capable of validating metrics to evaluate the application of resilience in response to a given event. For this purpose, we considered urban centers as a complex reference system.

This paper is structured as follows: Session 2 describes and contextualizes resilience and presents the dimensions; Session 3 presents the conceptual map containing the dimensions. The last section shows some comments and final considerations.

THE RESILIENCE AND ITS DIMENSIONS

Urban centers are undoubtedly considered as a living, pulsating complex system and from an organizational perspective are born in a certain place and have their own structural dynamics, where it is possible to distinguish two independent structures: the organization itself and its environment (Maturana and Varela 1987). The authors emphasize that the modifications are triggered by the disturbing agent, but determined by the structure of the disturbed system. Consequently, the environment and the organization in observation act as mutual sources of disturbances and trigger mutual changes of state. Additionally, it is important to cite the existence of a gap between the long-term disaster recovery purpose and the current implementation practice. This gap is motivated by the fact that the nature of the disaster recovery process changes over time. Initially it develops from a complicated set of interrelated, urgent but essentially predictable problems in the short-term response phase, culminating in a typical problem of complex systems (Blackman et al. 2016). Therefore, the maintenance of organizations depends on the compatibility between the organization and its environment and from this interaction emerges the concept of adaptation. However, this adaptive behavior is closely related to the concept of resilience. As Béné (2013), resilience results from the synergy between three capacities: absorption, adaptation and transformation. These capabilities operate with different intensities in order the system graduates its response to shocks and stresses. It should also be noted that the transition from absorptive resilience to adaptive and transformative resilience has an increasing cost and the risk assumed by the system also increases. Figure 1illustrates these three capacities depending on the type of response regarding the intensity of the shock.

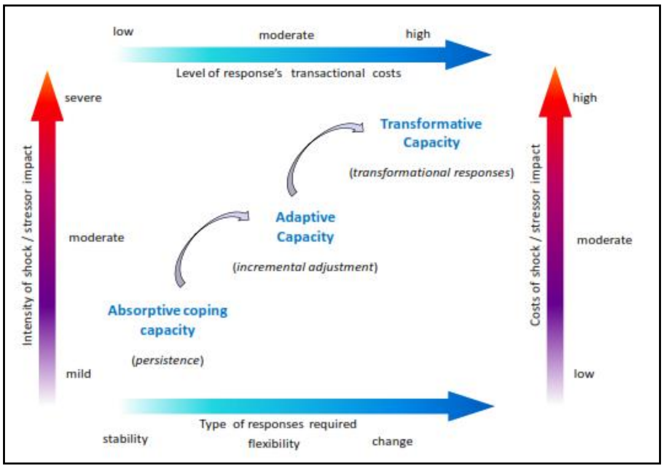

Figure 1 – Conceptualization of resilience in relation to its constitutive elements - Source: (Béné 2013)

It is inappropriate to dissociate resilience in urban centers from the resilience of individuals. For that matter, today both individuals and organizations seek flexible behavior as a way to deal with their respective environments. That is, bureaucratic rigidity and blind routine are rejected and workers are encouraged to be agile, innovative, to take risks continually and actively engaged in problem solving through collaborative activities carried out in teams or semi-autonomous groups. This set of attributes requires workers to be constantly concerned with educational and professional improvement, as well as demanding changes in their psychological processes, leading them to innovative and resilient attitudes. In addition, it is important to note that resilient actions are dynamic. That is, successes experienced in the face of certain situations strengthen the competence to deal with future adversities. Therefore, the object of action becomes a relevant dimension capable of qualifying resilience and unfolds in: resilience in the individual and social resilience, the latter covering cities, companies, organizations, communities and other social groups.

Indeed, resilience has become a central theme in the definition of security policies at the most diverse levels of the social structure. Governments, organizations, communities and individuals are increasingly concerned with developing a set of competencies that can restore their balance state in response to likely disruptive events. This desired competence is translated into actions to be performed by each component of the given system and, above all, must be interpreted based on three fundamentals with harmonic performance, according to table 1.

Table 1 – Foundations for the exercise of competency – Source: The authors

Foundations	Description
Knowledge	Concerns the knowledge needed to support the decision-making process to deal with the particular disturbing event.
Ability	Refers to the option for the best strategy of action to face the disturbing event.
Attitude	Refers to the option for the most appropriate moment to operationalize the resilience strategy.

However, Longstaff *et al.* (2010) state that the daily lives of individuals and organizations revolve around complex systems over which they have little or no control, such as transportation system, electrical system, communication system, and others. In addition, the inherent efficiency required by current complex systems tends to reduce their resilience because redundancy and diversity are discouraged. Another important point is that few complex systems are designed considering resilience as a project requirement. Therefore, it is acceptable to assume that the ability of these systems to recover after a traumatic event has a direct impact on the recovery capacity of a given organization. Thus, the complex systems that make up the infrastructure of urban centers acquire unquestionable relevance in the response to disastrous events.

In fact, resilience is a concept widely debated by researchers from the most diverse areas of knowledge; however, there is still no precise definition for this concept, its attributes and also how to operationalize it in the most diverse domains. In summary, the greatest theoretical challenge lies in integrating the multidisciplinary aspects embedded in resilience (Jabareen 2013). At that moment, another qualifying dimension is evidenced, in relation to resources demanded and consumed in the process of resilience: internal or external to the system.

Also, according to Longstaff *et al.* (2010) there has recently been a shift in focus that redirects research interest to investigate aspects of resilience related to a system's ability to anticipate a particular unwanted event. Consequently, resilience would be understood as a combination of (proactive) prevention activities coupled with activities in response to traumatic (reactive) events, in order to preserve and/or rehabilitate the fundamental functions that characterize the system. Ratifying this understanding, Boin & Eeten (2013) typify resilience by two elements: (1) after the occurrence of a traumatic event (2) the organization manages to recover acceptable levels of normality. The first element emphasizes that the disturbance may supplant the absorptive capacity for which the system was designed. While the second element unfolds not only in the system recovery, but also in the system's ability to emerge more strengthened from the disturbing event. As a result, resilience can be considered from two perspectives: precursor resilience that combines the system's ability to accommodate changes or the ability to absorb shocks smoothly and the resiliency of recovery that combines the abilities of the system to respond to events in a singular and unique way. Therefore proactive resilience has a conceptual similarity to precursor resilience, as well as reactive resilience with resilience of recovery. These similarities suggest the existence of another beaconing dimension of resilience, as for the way of application: proactive or precursor and reactive or recovery.

It should be noted that resilience can cause different behaviors in each of the components of the system. Eventually one component may assume functions of another, perhaps more affected by the traumatizing event. Thus, the system maintains its functional characteristics, despite the internal redistribution of functions. This fact evidences the importance of the system to keep track of the degree of criticality of each of its components as a way of identifying which of them could be discarded without the system losing its main functions. A continuous measurement of the state of each of its components and the interactions between them is therefore necessary. In this way, the creation of indicators to measure resilience becomes an activity of high importance, since these indicators, besides being one of the main resources to subsidize definitions of priorities in the planning activity, are also fundamental for the decision making process. Moreover, it is important to emphasize that the indicators reveal not only the relative position of the phenomenon under measurement and evaluation over time but also the direction and magnitude of the change (Cutter et al. 2010). However, these measurements are not trivial because they imply cost increase and are deeply dependent on the possible disturbing event, although the authors assert that independent metrics are ideal (Béné 2013).

Figure 2 presents the resources considered relevant in the development of resilient communities. The robustness resources cover the objects, conditions, characteristics and energies available to the population. On the other hand, adaptive capacity concerns the abilities of individuals and groups to maintain a memory of their experiences and to be able to learn from this past by deriving innovations and improving interaction not only between the components but also with the environment in order to improve the lessons learned and the capacity for self-organization or reorganization (Longstaff et al. 2010). These considerations, complemented by Figure 1 reinforce the idea that resilience can also be dimensioned according to its strategy of action: absorption, adaptation or transformation.

Organizations undoubtedly use all their resources to nullify or reduce risks to their permanence in the market (environment). For that, it is necessary to monitor not only the dynamics of the environment but also the internal dynamics of the organization. In this way, strategic planning is seen as one of the main instruments guiding corporate actions, because it prescribes the initiatives to be carried out in certain circumstances with the aim of leading the organization in the direction of its strategic mission (future). Nonetheless, Davoudi *et al.* (2012) introducing the concept of evolutionary resilience informs that some complex systems may change over time, with or without external disturbances. In this respect, resilience is not conceived as the return to normality, but rather in the ability of the system to change, adapt and transform itself in response to stresses and tensions, reaching a new stage of equilibrium. Therefore, evolutionary resilience proposes a new interpretation for the concept of resilience, since it recognizes that the seemingly stable state we see around us in nature or society (environment) can suddenly change and become something radically new, with characteristics that are deeply different from original. Thus, the behavioral history of the system is no longer a reliable indicator to predict future behavior, even if in similar circumstances. This perspective challenges the adequacy of conventional planning in extrapolating the past in order to assess future trends, reduce uncertainties or future risks.

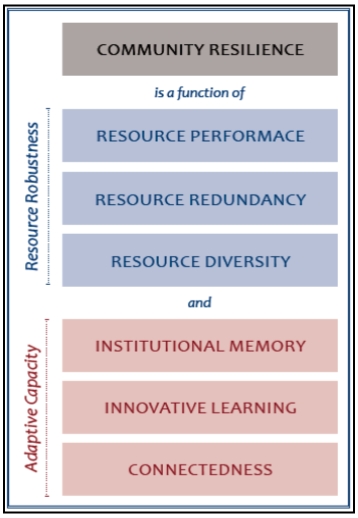

Figure 2 – Aspects of Community Resilience – Source: (Longstaff et al. 2010)

The model presented in Figure 3 illustrates the four distinct phases of changes in both the structure and functions of a complex system: growth or exploration, conservation, liberation or creative destruction and reorganization. The first cycle concerns the emergence, development and stabilization of the structure and functions of the system, while the second cycle refers to possible rigidity and decline, while at the same time the system opens up to new and unpredictable possibilities. This implies a cyclical process in which the ripening of systems leads them to reduce their resilience and they become "an accident to happen". When the system collapses, a window of opportunity opens with new configuration alternatives. It is important to emphasize that turning a crisis into an opportunity requires a great deal of preparation and maturity, which depends on the ability to imagine future alternatives. Thus, planning means preparing for an innovative transformation in time of continuous and unpredictable changes. Therefore, this process encompasses the concept of resilience because the act of planning must be based on a systemic interpretive perspective of the reality of both the organization and the environment as a way to obtain the best set of actions aiming at the adequacy of the organization to that new configuration of the environment. Thus, to be resilient in the urban context is to act in a preventive way so that shocks bring the lowest possible risk to the city. In fact, it is the constant learning that makes the city and its citizens less fragile, since each shock leads to the incorporation of new learning.

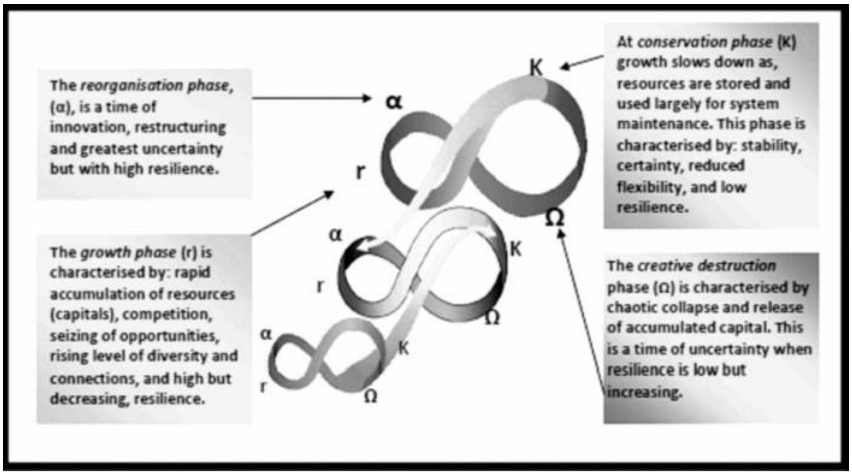

Figure 3 - The panarchy model of adaptive cycle - Source: Davoudi, et al (forthcoming) adapted from Holling and Gunderson (2002, pp. 34–41) and Pendall et al (2010, p. 76)

In fact, public policy can be more effective if it is geared toward improving system resilience and reducing its vulnerabilities. Therefore, planning is seen as a complex activity that incorporates interpretations not only about the system under analysis, but also about the environment, in order to identify the best way to guide the system to the desired path in a context of uncertainties. Therefore, it is inevitable to register another dimension for resilience, with respect to the predictability of the event: planned or unplanned.

From the point of view of the individual, Grotberg (1995) states that resilience is a universal capacity that allows a person to prevent, minimize or overcome the adverse effects of adversity. In this way it is necessary a series of abilities that the individual develops during its growth and is based on three sources, as shown in the Table 2.

Table 2 – Sources of resilience – Source: Adapted from (Grotberg 1995)

Element	Description
I Have	Represent external supports and resources that promote resilience, such as: reliable relationships, structure and stable social rules, incentive to act with autonomy, and others.
I am	Represents the internal factors to the individual and the internal forces (feelings, attitudes and beliefs) that provide the resilient attitude: kindness, empathy, altruism, self-esteem, and others.
I can	It represents the social and interpersonal characteristics, such as: communication, interaction in solving problems in society, managing impulses and feelings, seeking reliable relationships.

These resources act continuously and with different intensity in the individual. On the other hand, the feedback process triggers adjustment reactions to possible nonconformities resulting from the interaction of the individual with its environment. In short, education assumes a preponderant role in all this dynamics.

In these terms, resilience is a psychological process that seeks to balance risk factors with protective factors; since the balance between: stressful events, threats and adverse conditions that lead to vulnerability and, on the other side, the forces, skills, capacity for reaction and coping, that make up the individual invulnerable or resilient.

THE CONCEPTUAL MAP OF DIMENSIONS

An analytical environment is fundamental to support the decision-making process. For this, it is necessary to specify dimensions in order to delimit metrics generated in function of certain facts of the real world. In this way, the dimensions cited above are represented in blue on the presented conceptual map shown in Figure 4. These dimensions act together in the recovery of the system. Thus, this fact suggests that any future private study should be delimited from a combination of these dimensions. It should be noted that the resilient behavior is closely related to a certain event. Thus, the strategy for a resilient behavior is defined by the system as a function of this motivating event.

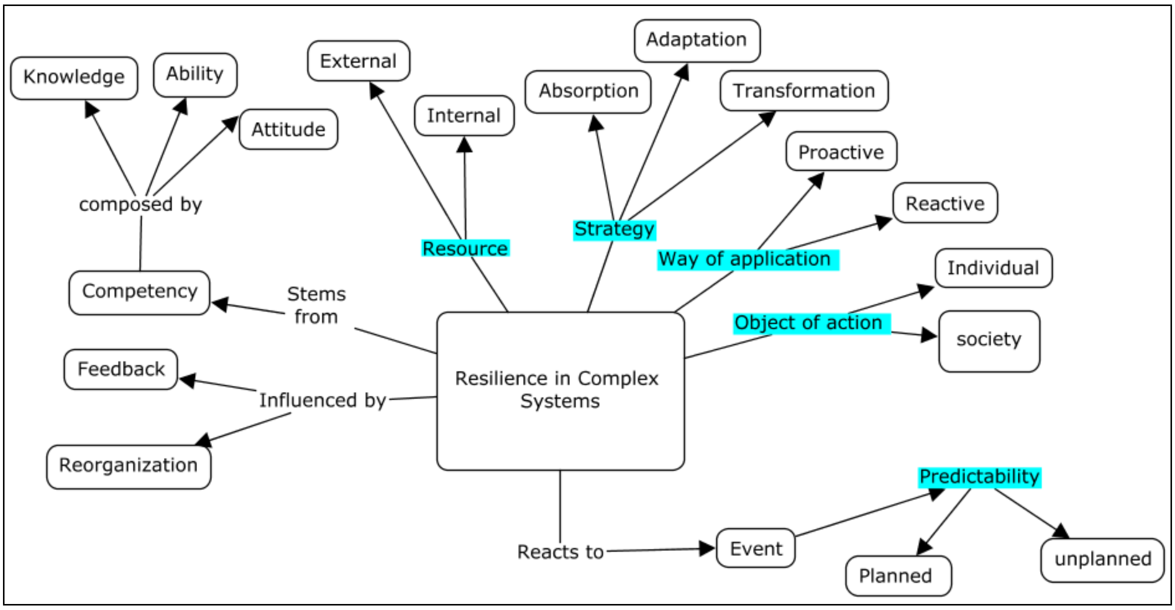

Figure 4 - Dimension map for complex systems – Source: The authors

The "Resource" dimension informs the source of the resources applied by the resilient action and can assume the values: Internal or external to the system. It should be noted that in some situations, systems require external resources to perform resilient actions.

The “Strategy” dimension characterizes the behavior of the system in resilient actions and can assume the values: absorption, adaptation or transformation. It is interesting to note that some components of the system may adopt different strategies or even change their strategy depending on the intensity of the impact caused by the disturbing event.

The “Way of application” relates to the moment when the resilient action was executed and can assume the values: proactive or reactive. The proactive resilient behavior concerns the system's attempt to anticipate the disturbing event and thus reduce or even nullify the impact of that event. On the other hand, the reactive behavior is triggered after the occurrence of said event.

The “Object of action” dimension informs if the resilient action was executed by an individual or a certain society. It is intuitive to think that a set of resilient individuals forms a resilient society, but this relationship is not linear.

The “Planning” dimension informs whether the disastrous event was planned or not. It should be noted that the actions and events foreseen in a planning are directly related to proactive resilience, since the plan means an attempt to anticipate a particular event of interest.

Finally, it is fundamental to emphasize that the feedback and reorganization dynamics have a strong influence on the way in which these dimensions will act in the recovery of this particular system.

FINAL CONSIDERATIONS

It is true that research on resilience has been intensifying in the most diverse areas of knowledge and this fact expands the possibilities of new research approaches. Nevertheless, there are still complex issues such as: What properties should complex systems stimulate to reinforce resilient actions? Are organizations composed of resilient people also resilient, since as relationships are non-linear?

Different forms of resilience require different profiles, structures or processes. In addition, the relationships of the complex system with its environment increasingly appear to be a crucial point in the final results of a resilient attitude where individuals are the main key.

It seems to be a consensus that a good interpretation of the facts is fundamental characteristic for both resilient organizations and resilient individuals. That is why, any research initiative will be welcomed in order to improve and measure the various hypotheses of interpretation of the facts. Thereby, the dynamics of scenario analysis is an important resource to be explored by the scientific community.

Finally, this work presented an exploratory study aiming to define a set of dimensions capable of delimiting metrics designed to measure the resilient behavior in the face of a certain disastrous event. The authors intend to proceed with the study on metrics and dimensions capable of measuring resilient behavior. Consequently this is the beginning of a long journey.

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Deducing Complex Scenarios for Resilience Analysis: Application to the Franco-German High Speed Train Network

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ABSTRACT

The present work is part of the project RE(H)STRAIN[1] which investigates security and its impact on the resilience of the Franco-German high-speed train network in case of terrorist attacks. To improve the capacity of this network to recover a normal functioning after a terrorist attack, appropriate security measures must be determined. To do so, the project investigates, in a scenario-driven holistic approach the entire terrorist sphere of possible actions. Terrorism threat is first defined as a set of single attacks called vignette attacks represented by the triplet actor – weapon – target, then complex attack scenarios are built considering combination rules detailed in this article. In this regard, this work aims at providing end-users with an approach to automatically deduce a set of formalized, consistent and plausible complex attack scenarios to allow in further steps to analyze and improve the resilience level of the high-speed train transportation infrastructure.

Keywords

Resilience, transportation infrastructure, scenario modelling, terrorist attack, risk assessment.

INTRODUCTION

In the last decades, terrorist attacks have increased in Europe and are even more frequent in the last years (Neubecker et al. 2016). Attackers seem to act with intelligence; they plan their assaults and select their targets according to strategic and tactical goals: achieving a maximum of damage (human, organizational and economical), generating fear and horror and obtaining a powerful impact in the media. According to these goals, transportation infrastructures represent appealing targets. The Franco-German high-speed rail transport system is such an attractive target because of its strategic European dimension: its worldwide known advanced technology provides it with a high symbolic impact and the economic consequences it may engender once attacked can be very important.

The high-speed rail system is also very vulnerable. It comprises several potential targets: a large proportion of tunnels and bridges, high density of people in stations and in trains and the technical gaps linked with high speed (signaling, cyber-attacks, derailment, etc.). The cross-border characteristic of the high-speed rail network also emphasizes its vulnerability because it implies collaboration of systems which are different both technically and organizationally. The train network is above all an open system that must be available and accessible

1 «Resilience of the Franco-German High Speed Train Network » Franco-German R&D project funded by the French National Agency of Research (ANR) and the German Federal Ministry of Education and Research (BMBF)

without restrictive individual controls, this makes it a target that is very hard to protect. Compared with the high safety standards of the Franco-German high-speed rail system, the deployed security means against terrorism need to be improved. In this regard, and in the continuity of Europe's effort to coordinated counter-terrorism programs (Fritzon et al. 2007), the RE(H)STRAIN project investigates how the resilience of trains and related infrastructure of the Franco-German high-speed public passenger-transport network can be increased against terrorist attacks and ultimately how to make the rail network a less attractive target.

To improve the capacity to recover a normal functioning, of the high-speed rail network, after encountering an attack or a sequence of attacks, the project investigates, in a scenario-driven holistic approach, the entire terrorist sphere of possible actions. All security measures and systems aiming at prevention[2], mitigation[3] and recovery[4] are also considered. The aim of the project is to provide the system with a line of defense to prevent the attacks from occurring and, should it happen, to mitigate their consequences as much as possible. Security measures will be defined and evaluated against different terrorist attack scenarios derived from historic terrorist attacks.

In order to determine appropriate security measures and analyze their effects, terrorism threat has to be considered in its most complex manifestation as attacks are very likely to happen simultaneously or in a short interval of time (9/11 New York attacks, 11/2015 Paris attacks). Therefore, the present work aims to build complex attack scenarios. Each complex scenario represents a set of parallel and/or sequential attacks with their corresponding defense measures. It addresses certain threats and risks upon which the resilience of the railway system can be analyzed and enhanced.

The aim of this work is to provide end-users with an approach to automatically deduce a set of formalized, consistent and plausible complex attack scenarios, analyze and test the impact of the performance level of the defense measures to allow in further steps of the project to analyse the resilience of the high-speed train transportation infrastructure considering the resulting scenarios. The remainder of this paper is organized as follows. In Section 2, a brief review of studies considering the terrorism risks and enhancing the resilience of transportation infrastructures against such risks is presented. Section 3 depicts the preliminary works to determine the terrorism threat and the train network vulnerabilities conducted in the RE(H)STRAIN project. Section 4 presents the complex scenario deduction approach applied on a set of identified attack scenarios against the railway transportation systems. The paper closes with a conclusion and the presentation of future works in Section 5.

RESILIENCE TO TERRORISM RISK - A BRIEF REVIEW

Transportation systems are considered as critical infrastructures (Moteff et al. 2003). Their networked character makes them highly vulnerable to any disturbance as the latter can result in widespread and important losses. Many studies have analyzed the damages related to terrorism related events threatening the well-functioning of such infrastructure typically through risk and crises management studies (RiKoV 2015; Khoudour et al. 2011; Milazzo et al. n.d.; Willis 2007). In the last decade, studies of more overarching approaches are aiming to improve the resilience of these critical infrastructures. Against uncertain events, prevention, planning and traditional top-down crisis management are limited and there is a real need for resilience (Boin and Mcconnell 2007) especially against terrorism threat (Cox 2008). To be resilient, the infrastructures are engineered or improved to inherently absorb disturbance, safety and security measures are analyzed and chosen to be implemented in accordance to their ability to achieve a quick and efficient recovery. Several studies aim to assess the level of resilience of transportation systems (Berche et al. 2009; Cox et al. 2011; Dorbritz 2011; Leu et al. 2010; Miller-Hooks et al. 2012; Jin et al. 2014; Bruyelle et al. 2014) providing strategies to reach an acceptable level of resilience.

The high speed train network is a Transportation Infrastructure of particular importance. Its vulnerability to terrorism threat is an issue that is widely tackled because of past events (White 2003) and its high symbolic of the European modern society. The need for the development of an effective and acceptable engineering response to terrorist attacks on railway systems was emphasized in (Powell and Fletcher 2011) by examining past terrorist attacks information, proving it to be the potential target to upcoming attacks. Therefore, a number of studies focuses on the protection of train networks infrastructures against attacks aiming for instance to determine the risk due to explosions (Larcher et al. 2011) or to improve the design of railway stations to reduce such risks (Jones 2011). Moreover, developments of remote detection and protection sensors that can be implemented for rail security system against terrorist attacks are currently being undertaken (HAMLeT 2016). In fact, the RE(H)STRAIN project emphasizes on not violating societal standards in the matter of accepting security

2 The act or practice of avoiding the arrival of a malicious act

3 To make (something) less severe, harmful, or painful. To minimize its effects.

4 The act or process of coming back to an acceptable state after a period of difficulty.

measures in the context of public transportation (Brauner et al. 2013). A security system which includes such remote technologies, would allow detecting terrorists on their way to their point of attack, without implementing individual security control of all passengers, thus maintaining the character of an “open” system that characterizes the railway network. Insofar, the implementation of airport-like security in the railway network would fail and disturb the functioning of the system. Today, no preventive security measures are implemented in the Franco-German high-speed rail system allowing it to maintain its “open” mass-transport system characteristic. The focus of the resilience strategy in the RE(H)STRAIN project is to enhance prevention and mitigation by means of a remote sensor network along with organizational security measures which allow combining preventive security of a closed system with the convenience of an open system for passengers.

PRELIMINARY WORKS FOR SCENARIO-BASED RISK ASSESSMENT OF THE HIGH SPEED TRAIN NETWORK

Increasing the resilience assumes decreasing the risk by, in the best cases, avoiding its origin, or should it happen, minimizing its effects. Accordingly, a risk assessment analysis is conducted in the RE(H)STRAIN project, along with recovery and mitigation strategies, as a basis for the resilience analysis (Schmitz 2016). The risk assessment is performed applying a method developed in the RiKoV project (RiKoV 2015), a study about risks and costs of terrorist threats against the rail-bound public transportation in Germany. It is advocated that the conventional view on risk determines the risk as a product of the occurrence probability of a damage event and the amount of damage. But since it is rarely possible to draw conclusions from past terror events to make predictions about possible future events, there are no meaningful statistics regarding the frequency of terrorist attacks to determine the occurrence probability of a terrorist attack (Wiens et al. 2014). Therefore, the occurrence probability is replaced by a function of the parameters “terrorist threat” and “vulnerability” where terrorist threat is a function of intention and capability of a terrorist.

The risk assessment in RE(H)STRAIN relies on a scenario-based threat analysis to cope with the scarcity and non-availability of statistic information. The spectrum of threat is defined in terms of plausible scenarios depicting the sphere of the terrorists’ possible actions as well as possible security measures for the prevention and mitigation of the consequences of different terrorist scenarios. Furthermore, the scenarios help to point out possible interdependencies and weak points. In fact, the vulnerability of the targets in the high speed train network depends not only on the problem of free access but also on the susceptibility of the target to the effectiveness of the attack means. The latter depends on the performance level of the implemented security measures.

In this regard, we present, in the following, the working method for the threat and vulnerability analysis conducted in the RE(H)STRAIN project. Threat and vulnerability of the system are investigated using a “Vignette”-approach for scenario-based threat analysis, where a Vignette represents the attack of a particular terrorist type on a particular target with a particular type of weapon susceptible to be used by the attackers. It is the smallest basic scenario (atomic). A set of vignettes is defined and a general execution process of an attack scenario is proposed to determine possible points of intervention for security measures. These information represent the input to our complex scenario deducing approach that allows, in further steps of the project, to determine not only the vulnerability of the high speed train network against a single attack, but also its vulnerability to a set of attacks happening simultaneously or in sequence in a short interval of time.

Attack Vignettes

In the Vignette approach, the set of potential targets, weapons and attackers’ profiles is defined on the basis of an evaluation of historical attacks and emerging trends performed against railway systems (Neubecker and Steyer 2016) crossed with the analysis of the Franco-German high speed train infrastructures (Lotter et al. 2016).

The train network infrastructure has been analyzed, considering its different constituents, their characteristics in term of function, location, capacity, responsibilities, etc. The retained potential terrorist type of targets are: high speed trains *en route*, train tunnels, train bridges, train platforms, train air conditioning systems, stations’ concourse, elevated train stations, escalators, lockers, control and command centers and signal boxes. The historical analysis of 158 past assaults against railway systems perpetuated, all over the word, from 1990 to 2015 (such as the sarin attack on the Tokyo subway 1995, the 2004 Madrid train bombing, the 2005 London bombings, the 2008 Mumbai attack etc.) concluded that attacks are executed by intelligent actors, operating in groups or individually with possible suicidal intentions. A spectrum of weapons was identified, ranging from mechanical means over all types of explosives, small arms and chemical means. Considering emerging trends and vulnerabilities, additional means of attack are added, such as cyber/hacker techniques, dirty (radioactive) bombs and bacteriological means.

Based on the selected set of targets and weapons, more than 30 reasonable combinations of the elements actor target and weapon have been defined (Neubecker 2016). For example, a vignette describes the attack of a group of terrorists over a high speed train *en route* using mechanical means to interrupt tracks and cause the derailment of the train. Because the number of combinations is very large, the identified set of vignettes is only a small representation of plausible scenarios. The set of vignettes are supplemented by the description of the environment and a description of the terrorists' motivation, intention and activities when approaching an attack. Furthermore, the consequences of the attack (damage on infrastructures, injury to persons, time to recover the railway traffic) are defined based historical numbers and on the application of lethal ratio calculation techniques for a rough estimation of the losses.

Attack process and defense system

In order to determine the vulnerabilities and week points of the train network infrastructures against terrorist attacks and eventually, position appropriate security measures accordingly, the process steps defining the course of planning and executing of a terrorist attack is identified (Gabriel et al. 2016). Terrorists have proofed to be able to devise sophisticated operation plans and do long-term planning to achieve strategic and tactical goals. An intelligent actor enriches his prospects of success by a careful exploration of the target and assesses his approach to the place of impact. He may also practice his actions and correct them. Accordingly, based on a common planning cycle, the "Plan-Do-Check-Act" cycle, and TRADOC terrorist planning cycle (STRATFOR 2012; TRADOC 2007), a general attack process model was defined. It depicts in detail the different phases of a terrorist assault for any target environment, it roughly comprises:

- The planning phase, during which objectives are defined and information is gathered.
- The doing phase, during which approaching the target and executing the attack are practiced.
- The checking phase, which serves to identify problems and consider those during the planning.
- The acting phase eventually represents the actual execution of the real assault (Gabriel et al. 2016).

The process model represents attacks performed by an individual or by a group. It applies to suicide assaults as well as assaults with subsequent escape. It also considers the fact that the actors will analyze the circumstances, including possible security measures, which may represent too much risk for the actors and thus could endanger the success of the assault. Figure 1 represents the main steps of the attack general model, and this in case of a physical attack, knowing that attack patterns for physical and cyber-attacks differ decisively from each other (Stewart 2012).

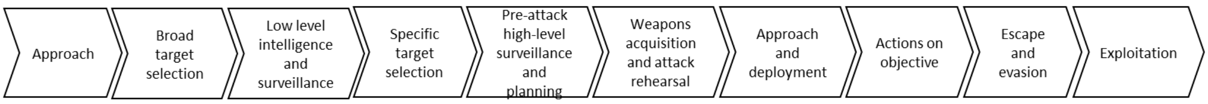

Figure 1. Main steps of the attack general model

In every phase of the process, the actor, and thus the attack, can be stopped by an appropriate line of defense; accordingly, 30 potential intervention points in the general attack process have been identified as positions to implement security measures. Also, for every intervention point, a set of potential security measures were identified. In total 110 preventive and mitigating security measures have been identified, to counter the evolution of the attack process or to attenuate its consequences. They include organizational measures such as preventive measures from radicalization, emergency management, preparedness and training of security staff, as well as technical measures of several types: video surveillance, access and baggage control, detectors, communication equipment, etc. It is of course important to investigate the effectiveness of these security measures against the terrorists' assaults, the assessment of their feasibility and performance will be undertaken in upcoming steps of the project.

On the basis of these findings, we examined and crossed the information related to the attack vignettes with the attack general model. We considered the detailed description of the proceeding of each attack vignette and deduced the corresponding activities from the attack general model that intervene in the attack vignette. Thus, we identified a set of sub processes (different versions of the attack general model) corresponding to the particularities of each attack vignette. Then, we deduced the set of intervention points included in each sub-process. As a set of security measures are identified for each intervention point, we identified the set of potential security measures along with their positioning during each attack sub-process, defining this way the corresponding defense system to be implemented against each attack vignette.

DEDUCING COMPLEX ATTACK SCENARIOS

Based on the set of vignette scenarios, their according process models and the defense system identified against each attack scenario, we propose to develop a set of complex scenarios. Each scenario addresses certain threats for civil security in the Franco-German high speed train network. Insofar the latest attacks that target the train network are acted as a set of attacks, each one is considered in this work as a single attack vignette. For instance, the July 2005 London attacks, where two underground suicide bomb attacks were perpetuated or the March 2004 Madrid bombings where 10 bombs exploded in a train and 3 additional bombs that were to explode with delay were neutralized in Atocha station. It is therefore important to represent terrorism threat in its most complex manifestation and consider attacks perpetuated as a set of triplets actor – weapon – target.

We propose to rely on a model-based simulation for resilience engineering and assessment, to tackle the uncertainty dimension arising from terrorist risks. Our approach aims to automatically deduce a set of formalized, consistent and plausible complex attack scenarios in order to allow analyzing and understanding the threats and effects of complex attacks and, in further steps of the project, allow using simulation of the retrieved complex scenario models to test defense measures and thus support the resilience assessment and enhancement. We defined modelling and analysis concepts, adopting a systemic approach where the aspects to be considered and the knowledge that has to be captured for the resilience analysis of the train network are represented in several different modeling views (structural-informational (rail network), functional-behavioral, risks management, resilience analysis…).

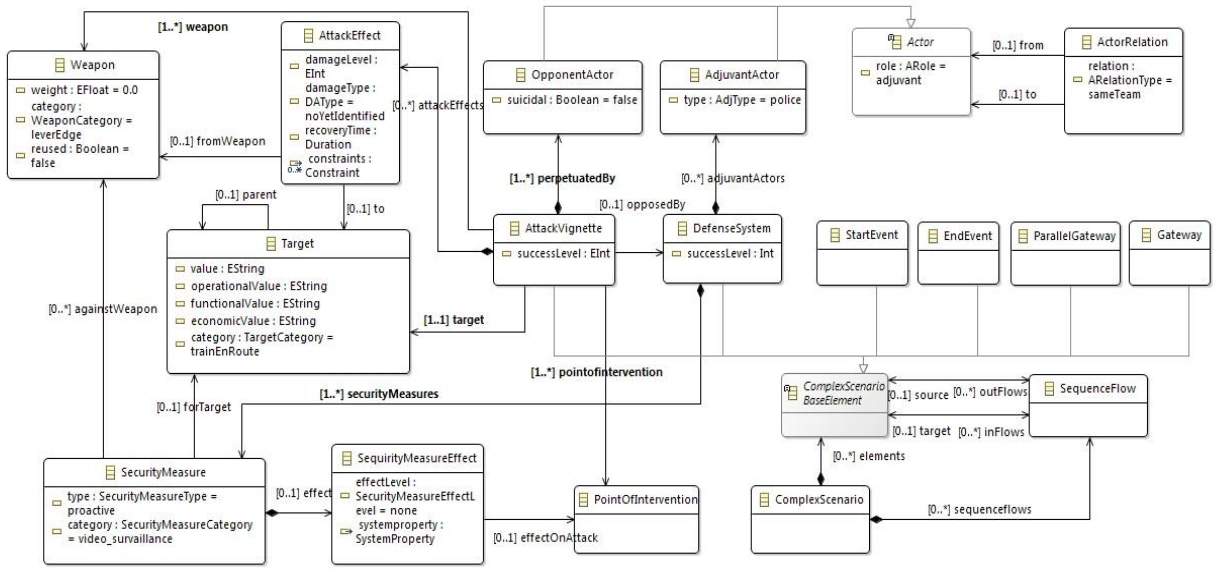

Figure 2. Attack and defense behavioral view model

The attack scenarios are represented with the use of the behavioral view model concepts (Figure 2.). The latter allow representing single attack vignettes by defining: (i) the opponent actors (terrorists) that perpetuate the attack; (ii) the targeted train network infrastructure and its characteristics, where the attack has only one target and (iii) the utilized type of weapon along with the effects it induces on the target. Each attack vignette is opposed by a **defense system** represented by a set of security measures each engendering an effect on the different points of intervention identified for the opposed attack vignette. A **complex scenario** is a process, i.e., a set of organised activities (sequence, parallelism) where every the activities depict attack vignettes followed by their corresponding defense systems.

A complex scenario must be a plausible, consistent description of the proceeding of attacks. Accordingly, we use the model as a support upon which we perform a consistency analysis to detect inconsistent situation where, for example, an actor is performing two different attacks on different targets in the same time frame. We combine attack vignettes according to composition rules determining the conditions that permit the construction for now of two types of combination of attacks: parallel attacks and sequential attacks.

The aim here is not to put all possible future attacks in each complex scenario. We define a set of complex scenarios each including a representative, likely to happen, sample from the total attack vignette space. In this regard, we rely on hypothesis presented in the following:

- In a complex scenario, parallel or sequential attacks are perpetuated in the same geographic area, i.e., one that requires the deployment of the same defense actors and efforts, for example attacks targeting a station and a train *en route* in the same city and not attacks happening in 2 distinct stations one in France and the other in Germany. Otherwise they are considered as independent attacks happening in the same time frame for perhaps a more important media impact. Thus, in order to consider all possible threats we assume that all the identified attack vignettes include targets of the same geographic area.

- Because of lack of information regarding cross border situations, we consider the attacks regardless of the country where they can be perpetuated (France or Germany).
- We suppose the parallel attacks to be executed by different actors or group of actors and the sequential attacks to be executed by the same actors or group of actors. The parallel attacks starts either simultaneously, within a short delay or even one after another (configuration 1. Figure 3.). In fact, even if attacks are perpetuated in a sequence, they are perceived as planned to happen in parallel. It may even be the case, where the actors firstly plan to execute synchronized attacks but end up having delays. A representation of a complex scenario in a sequence is only interesting if the attacks are perpetuated by the same actor or group of actors, where we can consider the threat that they represent if not captured. Therefore, we consider the sequence of attacks by more than one actor/group of actors as desynchronized parallel attacks.
- The possible process configurations of complex scenarios are attacks happening in parallel (configuration 1. Figure 3.), attacks happening in sequence (configuration 2. Figure 3.) or sets of sequential attacks happening in parallel (configuration 3. And 4. Figure 3.). Where, in the latter, an actor or group of actors involved in parallel attacks perpetuate more than one attack. Combination wise, it is of course possible to go further and build sequences from parallels of sequences… etc. but this would not be very meaningful for our context. As in the reality, attacks are eventually seen as several attacks happening on parallel or in sequence. Besides, a complex scenario is planned to be executed in a short interval of time (6 hours). We consider a situation such as the configuration 5. (Figure 3) as 2 complex scenarios that occur delayed by a larger period of time. They are then 2 different attack operations.
- Considering the effort (coordination, synchronization, logistics) needed to plan parallel attacks, the speed of spread of information nowadays, the possibility that the actors can be captured and the analysis of historical terrorism events and latest trends (9/11 New York attacks, 11/2015 Paris attacks…etc.) we follow the assumption that the plausible number of possible parallel or sequential attacks to be three attacks. In this case, configuration 4. (Figure 3.) represents the worst case scenario of attacks.
- Each attack vignette is opposed by a defense system (considered to follow the attack in the complex scenario process) consisting of a set of security measures. In the current stage of the project, we do not address the assessment of the effects of security measures, i.e., their performance level regarding the attack. Therefore, we represent the success of the defense system in a very simple way. Ten levels of success are defined. They correspond to the ten main phases of the attack vignette process (Figure 1.). For example, the value of the level of success of the defense system against a given attack is 8 means that the step of the attack "actions on objective" couldn't be achieved, i.e., the opponent actors couldn't trigger their weapons and perform the attack. Accordingly, there are no damages to deplore as a consequence of this attack and the opponent actors are captured.

Following these assumptions, we developed an analysis algorithm (Figure 4.) to automatically deduce complex scenarios from the set of 33 identified attack vignettes (Neubecker 2016) and their identified defense systems. To guarantee the plausibility and consistency of the complex scenarios, the algorithm implements the following constraints or rules to build the attacks combinations:

- An opponent actor or group of actors perform one and only one attack in a set of parallel attacks.
- If it risks to be destroyed or contaminated by a first attack, a target is attacked only once in a set of parallel attacks i.e. no other attacks perpetuated on this target are considered for the current complex scenario. In fact, the risks of decreasing the prospects of success of the other attacks are high. There is also the fact of putting in danger the other attackers which may be in the lethal radius of the first attack.
- No derailment in parallel with another attack on the same train as it is very unlikely to plan such synchronized attacks, also the actors will not "risk" sabotaging the ultimate attack of derailment by performing another attack in the same train risking this way to stop the train before arriving to the derailment point.

- A single actor, once captured (the step "escape and evasion" didn't succeed – knowing that "actions on objectives" could have succeeded) and checked if he is not representing a threat any more (he is not in the possession of potential means of damage to his surroundings) cannot be the executer of any following attacks.
- No derailment (obstacles on a train *en route*) before a second attack on the same train *en route*. It is in fact more likely for attackers to preserve a target for an ultimate attack and not risk to be caught before the execution of this attack.

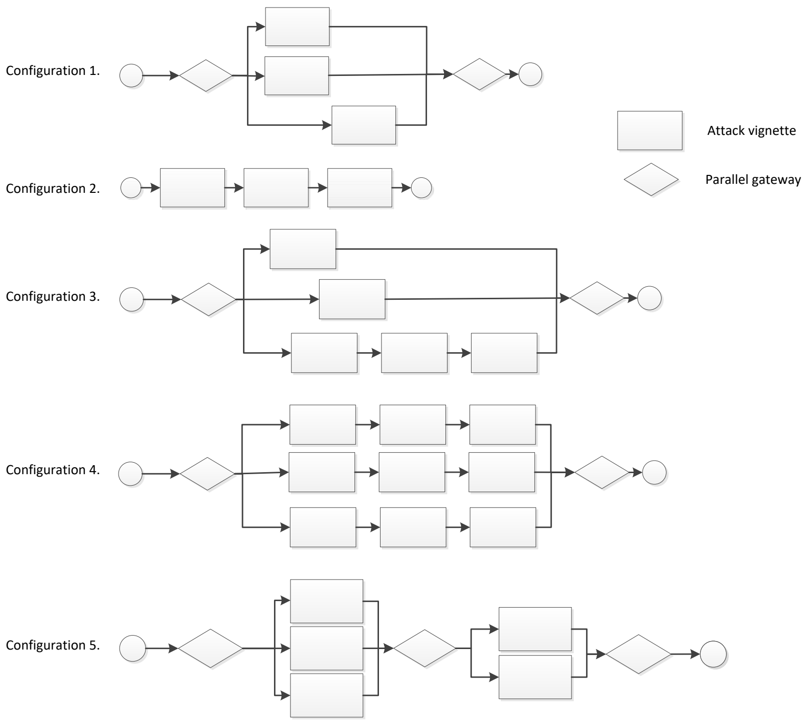

Figure 3. Complex scenarios configurations

- No chemical or bacterial attacks after explosion attacks on the same train *en route*. Of course, attackers do not plan attacks that risk decreasing the prospects of success of other attacks.
- If destroyed, i.e., the means of the attack can cause the destruction of the target and the step "actions on objective" of the attack succeeded, an infrastructure is no longer be the target of another attack.
- Suicidal actors, once checked if he is not representing a threat any more, can no longer be the executers of any following attacks.

We use these rules to determine whether or not attacks can be put in parallel or in sequence in each complex scenario. The algorithm consists of three main procedures used to combine the activities into different possible configurations to help build up the final set of complex scenarios. We first build a set of scenarios each constituted by parallel attacks ("Build parallel attacks" in Figure 4.). To do so, insofar the size of attacks does not exceed 3 parallel attacks in each complex scenario, we verify rule 1 to 3 for each vignette with each vignette of the set of remaining vignettes. If rules 1 to 3 are verified the vignettes are put in the same complex scenario of parallel attacks, knowing that if both the configurations of vignettes A and B: A parallel B and B parallel A exist only one is considered – the same in the case of 3 vignettes is parallel. Similarly, in the second procedure, we build sequences of attacks. We apply the rules 4 to 8 on the set of attacks to verify the possibility for these attacks to happen in sequence. After that, we consider the third possible configuration (configuration 3. Figure 3.) of attacks. In fact, the proceeding of the attack scenario can be more complex. We therefore propose to build parallels from the set of sequence attacks that are retrieved in "Build sequential attacks", where sets of sequential attacks can happen in parallel if their corresponding attacks verify the rules 1 to 3. Finally, we exclude, from the final set of complex scenarios, scenarios composed of only one attack vignette and duplications of scenarios.

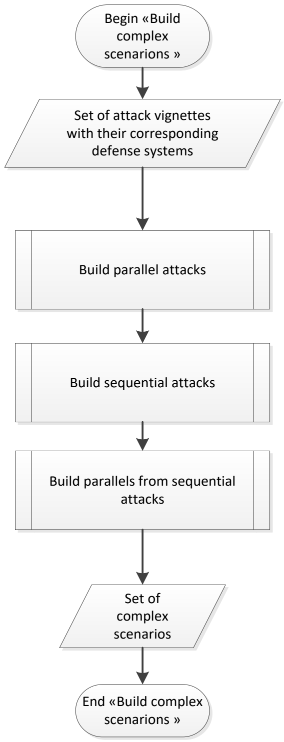

Figure 4. Deducing complex scenarios algorithm

The automatic generation of the complex scenarios facilitates significantly the task of combining attacks. Manually, it is difficult and time consuming to depict, or know when to stop, the possible attack configurations considering the important number of attack vignettes and the set of hypothesis and combination rules. From the initial set of 33 attack vignettes, considering the current configuration of the input data, the algorithm allows to deduce a set of 1563 complex scenarios. The results depend very much on the configuration of the input data. If all the attack vignettes are acted on different targets and by different actors, most the rules will be verified on the set of the vignettes and will not allow eliminating a lot of combination cases, resulting this way in a much higher number of possible complex scenarios. Moreover, the algorithm can integrate new attack vignettes that can be added to complete the initial set of attack vignettes. Other combination rules can be added and some can be loosened providing this way a different set of complex scenarios.

For such complex attacks a complex defense response must be implemented where defense actors and efforts have to be coordinated and deployed. Each complex scenario describes the frame conditions for several possible duels between attacks and defense systems. These scenarios represent a test base, for the resilience analysis, from which we can draw to perform simulations and test the selected security measures. Most importantly, the definition of such complex scenarios allows predicting the potential risks that the train network encounters after the occurrence of an attack, as all the possible following developments of an attack are depicted in the set of complex scenarios.

CONCLUSION AND FUTUR WORK

Threat and vulnerability analysis is a preliminary step towards resilience analysis. The present work contributes to a joint work conducted in the RE(H)STRAIN project. It aims at defining the threats against civil security in the Franco-German high speed train network by considering possible proceedings of attacks generated automatically into a set of formalized consistent complex attack scenarios.

In order to fully determine the vulnerability of the rail network we propose to analyze, in the next step of the project, the performance level of the selected security measures against each attack. To do so, operational decisional and technical performance indicators have to be identified for each security measure (such as: availability of the actors, accessibility, time of propagation of the information, detection probability… etc.). This allows measuring their performance level and thus their effectiveness against terrorist weapons considering the target environment.

The impact of the security measures have to be tackled in a lower level of granularity in the complex scenario process. In fact, the defense system can influence the actions of the attackers during the different phases of their attack plan and execution (Figure 1.) forcing the attackers to change their initial plan and producing this way an impact on the consequences of the attack. Accordingly, we propose to consider in future works detailed complex scenarios, where it is possible to zoom in the attack and detail the course of the attack considering the attackers reaction and behavior depending on the effectiveness of the implemented defense system. This implies considering conditional elements (exclusive gateway) in the proceeding of the generated complex scenarios.

ACKNOWLEDGMENTS

We would like to thank the French National Agency for Research (ANR) and the German Federal Ministry of Education and Research (BMBF) for the financial support they provided to this work within the project RE(H)STRAIN. We also address our acknowledgment to our French and German project partners[5] with whom valuable discussions and joint work on resilience analysis have been conducted.

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Social Media Studies

A Required Work Payment Scheme for Crowdsourced Disaster Response: Worker Performance and Motivations

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ABSTRACT

Crowdsourcing is an increasingly popular approach for processing data in response to disasters. While volunteer crowdsourcing may suffice for high-profile disasters, paid crowdsourcing may be necessary to recruit workers for less prominent events. Thus, understanding the impact of payment schemes on worker behavior and motivation may improve outcomes. In this work, we presented workers recruited from Amazon Mechanical Turk with a disaster response task in which they could provide a variable number of image ratings. We paid workers a fixed amount to provide a minimum number of image ratings, allowing them to voluntarily provide more if desired; this allowed us to examine the impact of different amounts of *required work*. We found that requiring *no* ratings resulted in workers voluntary completing *more* work, and being more likely to indicate motivation related to interest on a post survey, than when small numbers of ratings were required. This is consistent with the motivational *crowding-out* effect, even in paid crowdsourcing. We additionally found that providing feedback on progress positively impacted the amount of work done.

Keywords

crowdsourcing, Amazon Mechanical Turk, payment, motivation, required work

INTRODUCTION

When faced with a large amount of data that would be either computationally challenging or rely on human subjectivity to process, crowdsourcing is a popular approach to gathering information on solutions provided by humans. In particular, image analysis tasks—such as image labeling or rating—have proven to be particularly amenable to this approach. A number of projects over the past decade have taken crowdsourced approaches to acquiring labels for images, either for the sake of acquiring the labels themselves or as training data for machine learning techniques (von Ahn and Dabbish 2004; Raddick et al. 2010; Mitry et al. 2013). Within this area, crowdsourced image rating for mapping—especially in the context of disaster response—has recently arisen. Projects such as SandyMill[1] (a collaboration between the Humanitarian OpenStreetMap Team and FEMA) (Munro et al. 2013), Tomnod's involvement in GEO-CAN (Barrington et al. 2012), the Ushahidi-Haiti Project (Liu 2014), and Cropland Capture (Sturn et al. 2015) have all taken approaches to asking crowd workers to rate images for

[1]SandyMill forked an existing open source image sorting application, MapMill, developed by Public Lab and Jeff Warren. In SandyMill, crowd members sorted images taken by Civil Air Patrol of damage from Hurricane Sandy.

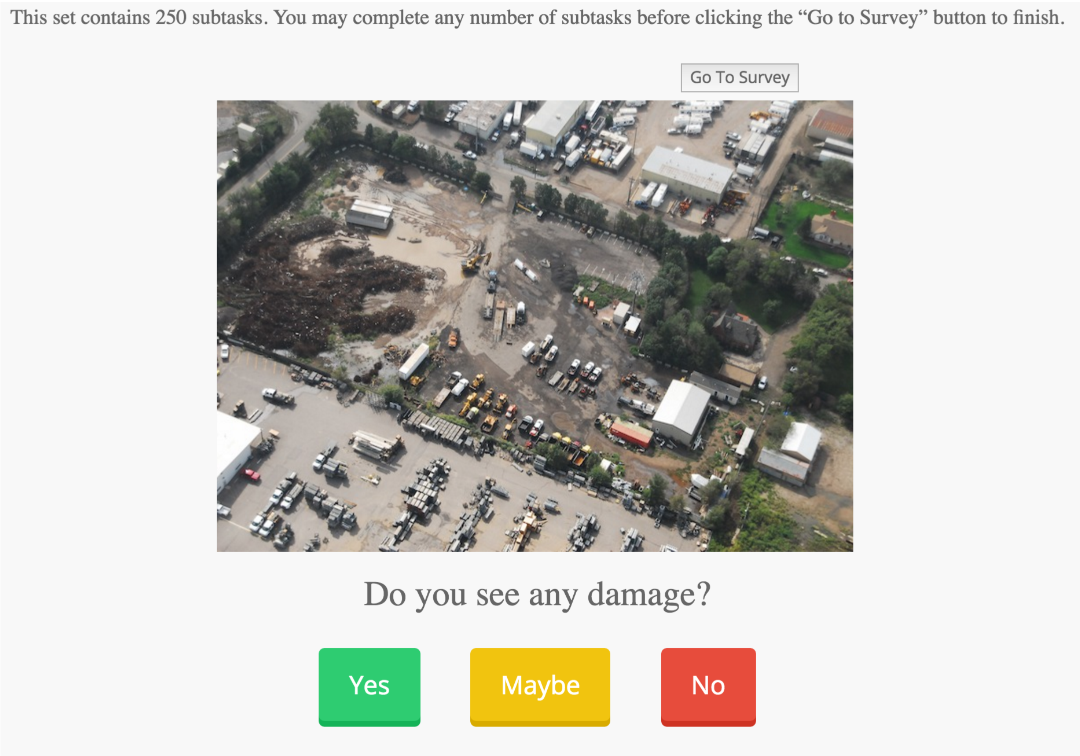


Figure 1. Screenshot of the image rating page used for our task. Instructions are shown along the top. In this condition, progress through the total set and progress through the required work are not available to workers.

the purposes of creating, improving, or annotating maps. "Space archaeology" is another emerging area for crowdsourcing image analysis, with projects such as Global Xplorer, a platform for analyzing satellite images (Global Xplorer 2016).

Crowdsourcing holds promise for applying human processing to the massive amounts of data that can be generated in the wake of disasters—either through paid work or volunteering. However, analysis of contribution patterns of participants in volunteer crowdsourcing projects generally indicate that most participants contribute little work, and that the bulk of the work is done by a small number of participants (Sauermann and Franzoni 2015; Sturn et al. 2015). This leads to relying on a few participants to disproportionately carry out the majority of the work, makes it less likely that projects will find such participants and be successful, and limits the amount of data that can be processed. Additionally, Munro et al. (2013) propose paid crowdsourcing as a cost-effective alternative when recruiting volunteers is not feasible; this may arise for less "prominent" disasters, which affect smaller areas, receive less media coverage and thus may attract significantly fewer volunteers. Such a comparison can be seen between two events in 2010: the Haiti earthquake, which received more than 3,000 news stories within the first 10 days, and the Pakistan floods, which received 320 broadcast news stories and 730 print news stories in the same timeframe (Brookings-Bern Project on Internal Displacement 2011).

Amazon Mechanical Turk (*MTurk*) is a widely popular online marketplace for crowdsourcing. MTurk allows *requesters* to post Human Intelligence Tasks (*HITs*) for *workers* to complete for payment. Although primarily intended for use as a paid crowdsourcing platform, recent work has shown that workers on MTurk are motivated by more than simply money (Kaufmann et al. 2011) and that aspects such as the framed meaningfulness of a task can impact measures of worker performance (Chandler and Kapelner 2013). Therefore, we considered MTurk as a means to recruit participants who may not be motivated purely by payment, but also voluntarily assisting in disaster response.

In order to gain insight into the motivations of workers on MTurk, and the interplay of paid versus volunteer work, in the context of disaster response, we ran a HIT on MTurk based on the MapMill project. MapMill is a citizen science mapping project that allows the uploading and subsequent rating of geotagged aerial images. Originally created in response to the Deepwater Horizon oil spill (Warren 2010), MapMill has subsequently been used in the aftermath of Hurricane Sandy, assessing damage and producing a heatmap of damage intended for use in directing relief efforts (Munro et al. 2013).

We developed a HIT that isolated the image rating portion of the MapMill project, which presented participants with a sequence of aerial photos of the Colorado flooding from 2013 and asked them to identify images containing damage. We posted a HIT on MTurk that used a *required work payment scheme*: workers were paid a fixed amount to rate *at least* some minimum required number of images; workers could then voluntarily continue rating images if they desired. Workers also completed a post-survey, which asked why they provided any additional ratings, in an open ended structure. We wished to examine the following research questions:

RQ1: What is the impact of requiring work versus not requiring work?
RQ2: What is the impact of providing feedback on progress?
RQ3: What different motivations do workers provide for their contributions in the project?

Within the HIT, we ran a multivariate experiment that varied two properties of the task. To examine the effects of required work, we varied the minimum amount of work required to receive payment: requiring no work, and requiring two different small amounts of work. To examine the effects of progress feedback, we varied whether workers saw a progress counter—toward their required amount of work and the total amount of work available. Since workers received the same fixed payment regardless of how many ratings they provided beyond the required minimum, we expected that any additional ratings would be provided for some reason other than payment, especially on the MTurk platform, where there are many other paying tasks available that might be a more lucrative use of a worker's time. Based on the *crowding-out effect* from psychology—where introducing an external reward can decrease intrinsic motivation and engagement (Lepper et al. 1973; Pretty and Seligman 1984)—we expected that paying for completing some work would generally have a negative impact on worker output and subjective experience. We also expected that showing workers their progress would have a positive impact on output.

After running the study, we observed that measures of productivity were generally improved by not requesting any work to be done at all, which is consistent with the crowding-out effect. Our observations were reinforced by the results of the open ended survey, which highlighted a switch in motivation from personal interest in the task to providing enough ratings, per the instructions. We further observed that the presence of progress feedback led to an overall increase both in amount of work and total time spent on the task.

This work contributes an empirical study to the growing understanding of crowdsourced worker motivations and behavior in disaster response. The study is consistent with motivational crowding-out, and the benefits of providing feedback on progress, in crowdsourced disaster response tasks. The open ended nature of the survey questionnaire about worker motivations allowed a wider range of elements to be identified, compared to standard multiple choice surveys, which proves encouraging for future research.

RELATED WORK

Crowdsourcing for Disaster Response

Crowdsourcing has featured prominently in disaster response scenarios as a means to help process the massive amounts of data that become available during these events. Efforts have been made in designing interfaces that will incorporate community-sourced intelligence into federal response operations (Crowley 2013). The evolution of crisis crowdsourcing led to the development of the Crisis Crowdsourcing Framework by Liu (2014), who also points to social, technological, organizational, and policy interfaces that need to be designed to guarantee an effective implementation of the framework. Goodchild and Glennon (2010) focus on the Santa Barbara wildfires that took place from 2007 to 2009 and how the community was able to contribute to disaster management through volunteered geographic information.

Aerial images are becoming increasingly important in disaster response. AIDR (Artificial Intelligence for Disaster Response), was initially designed to classify Twitter posts created during disasters using crowdsourcing (Imran et al. 2014). The platform was used to classify posts during the 2013 Pakistan earthquake. Ofli et al. (2016) extended AIDR to support aerial data captured via unmanned aerial vehicles (UAVs). Volunteer performance in rating aerial images was also examined in Mapmill, a community-sourced damage assessment project, following Hurricane Sandy. Munro et al. (2013) conclude that only four to six workers per image were required to ensure accuracy of the assessment, which can reduce the cost of aerial image assessment for future disasters. The use of Spatial Video Technology in damage assessment was also examined by Lue et al. (2014), where users reviewed video recordings of homes affected by the disaster. Inexperienced users were able to produce similar results to experts, suggesting the possibility of opening disaster response systems to a wider audience.

Finally, social media has been shown to be a potential source of information in disaster response operations. Tweets have been examined in assessing earthquake events near the islands of American Samoa and the city of Padang on Indonesia's island of Sumatra, in 2009 (Kireyev et al. 2009), as well as Hurricane Sandy (Kryvasheyeu et al.

Question	Choices
Can you tell us why did you complete the number of images that you did?	*(Free-response text area)*
Check all that apply:	*(Checkboxes to select any combination from:)* I did not understand the instructions. I thought I would get paid more. I thought my submission would not get approved.

Table 1. Survey questions and answers.

2016). Tapia et al. (2011) stress the need to overcome barriers in adopting microblogged data by international humanitarian relief organizations by introducing solutions that will ensure data reliability.

Crowd Motivation, Feedback, and Payment Schemes

Work in motivational psychology has established that *extrinsic* financial incentives can have a negative impact on *intrinsic* motivation (Deci 1971). This is commonly known as the "crowding-out" of intrinsic motivation (or "overjustification" effect). This effect has been explored empirically in many laboratory and field scenarios (Ryan and Deci 2000; Frey 1994). Other work has proposed that providing financial incentives may crowd-out intrinsic motivation to participate in research (Achtziger et al. 2015). Gneezy and Rustichini (2000) found that, when paying students a fixed amount to participate in an exam, adding a further small financial incentive reduced the student's exam performance relative to those who were not offered any further incentive; however, a larger financial incentive improved exam performance.

While tasks on MTurk involve payment, workers are motivated by factors other than money. Chandler and Kapelner (2013) found that framing an MTurk task in a more meaningful way led to an increase in participant engagement, as well as quantity of work, without a trade-off in quality. Kaufmann et al. (2011) concluded that although extrinsic motivation, in the form of payment, is present for MTurk workers, intrinsic motivation, such as skill variety, task identity, task autonomy, as well as community based motivation, is also significant.

However, Ho et al. (2015) found that performance-based payments may also improve quality, depending on the task. They argue that most MTurk tasks are *implicitly* performance-based, as workers consider that their work may be rejected if their performance is poor. Workers may come to a task with different notions of what is acceptable performance to avoid rejection. DellaVigna and Pope (2016) ran a large-scale study on MTurk, examining payment incentives and motivation, and found that even a very low payment did not notably crowd-out motivation; similar to other research on MTurk, they found that increasing piece-wise payment increased the quantity of work done. However, DellaVigna and Pope's task was quickly alternating keypresses, and thus may not be directly applicable to motivations in more "meaningful" tasks such as disaster response.

Previous crowdsourcing work has used a payment scheme with fixed payment for a set amount of required work. Khajah et al. (2016) paid workers a fixed amount to play a game for a minimum amount of time and then measured engagement as the amount of time played beyond that point, while Cai et al. (2016) paid workers a fixed amount to complete a small number of writing tasks.

Additionally, providing *feedback* on work is generally considered to improve worker motivation, as in the Job Characteristics Model of Hackman and Oldham (1976). Research shows that providing feedback on accuracy can improve the accuracy and quality of crowdsourced work (Riccardi et al. 2013; Dow et al. 2012).

Another form of feedback, *progress feedback*, gives workers feedback on the amount of work they have done towards a goal, without giving feedback on their accuracy. This can be particularly useful, as it does not require knowing ground truth for any tasks. In practice, this type of feedback may be more closely connected in Hackman and Oldham's model (1976) to *task identity* rather than what they term *feedback*, as it does not inform workers of their accuracy, but may give them a greater sense of contributing to a "whole" piece of work by filling the progress count.

Other work has examined the use of progress feedback in a crowdsourced setting. Toomim et al. (2011) found that workers preferred an interface that included text informing them how many more CAPTCHAs they had to complete to finish a HIT, but this feedback was combined with numerous other *aesthetic* changes in their comparisons. Chandler and Horton (2011) used artificial progress bars to indicate how close an image was to reaching its desired number of labels, and found that the positioning and balance of progress bars could be used to influence which

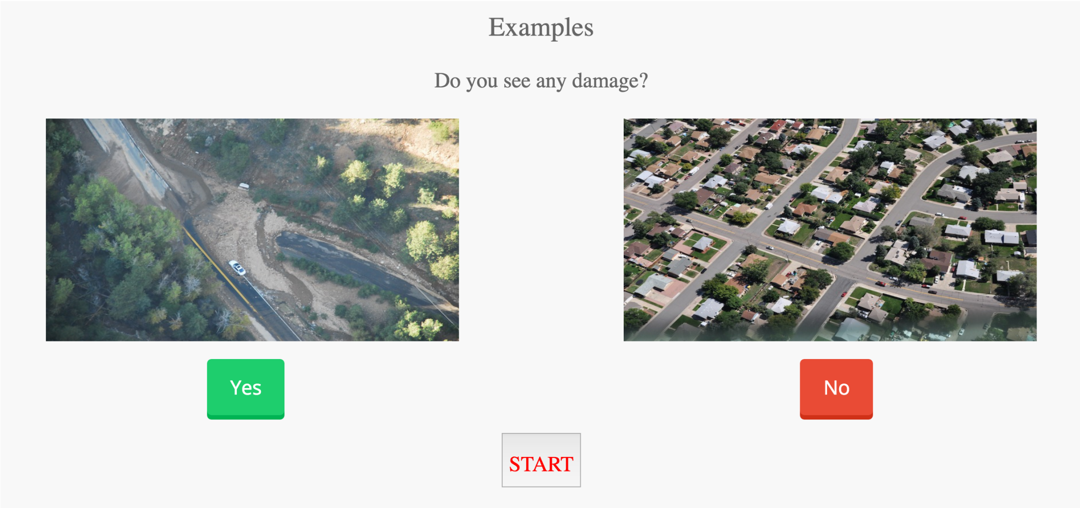


Figure 2. Screenshot of the training page used for our task.

image workers would provide labels for—generally increasing labeling for images that appeared to need more labels. Jacques and Kristensson (2013) found that the inclusion of a progress bar along with other "value proposition" elements (such as an example task) increased the conversion rate of workers who complete a HIT compared to those who are exposed to it.

TASK DESIGN

The motivation behind our task was to design a simple, user-friendly, and lightweight tool—inspired by the MapMill project—for participants to provide ratings for images, selected from a predefined set of possible ratings, to answer specific questions. We chose an image labeling task, as these are a highly popular and flexible method of crowdsourcing that requires less effort than other more complex tasks and can be used in a variety of settings. Using geotagged images of an area also allows immediate translation of responses for mapping purposes.

We posted a HIT on MTurk, which paid 50¢, titled:

> Disaster Area Map Image Labeling

The HIT description was:

> Label and categorize aerial images of disaster areas and answer a short 5 question survey on task.

The HIT keywords were:

> image; label; labeling; categorize; map

Because of the nature of the experiment, IRB approval was received. Upon accepting the HIT, subjects were informed that they were taking part in an experiment and were required to consent before proceeding. They were then provided with instructions on rating the images that appeared onscreen, including the minimum number of ratings (or *subtasks*) required. In order to counteract the variety of subjective beliefs about the amount of work required to be approved, the instructions explicitly stated that the submission would be approved if the survey was completed—similar to the "guaranteed payment" of Ho et al. (2015). The instructions were shown exactly the same to all workers except for the *conditional element*, which varied based on their experimental condition (described in more detail below). The instructions were:

> Click **START** to begin rating images. For each image, answer the question that appears beneath the image. When you are done rating, click the Go To Survey button to complete a short survey, after which your HIT will be completed. Please do not use your browser's back button while rating images or taking the survey. **If you complete the survey, your submission will be approved. This set contains 250 subtasks.** *[Conditional element of instructions, describing how much work was required, appeared here.]*

After an example for the types of rating, which acted as a small tutorial (shown in Figure 2), they then proceeded to rate images by answering damage related questions. When the required amount of work was completed, participants could either continue rating images or choose to complete the task by answering a short survey. If a participant rated all possible images, they were automatically taken to the survey.

Figure 3. Comparison of differences in task presentation among conditions.

In the survey, participants were asked to provide some feedback about the reasons that motivated their performance. The survey included two questions about motivation: the first question was a free-response question about the amount of work they did, and the second question included checkboxes allowing workers to indicate what we expected might be points of confusion about the instructions or payment scheme. A summary of the survey questions can be found in Table 1.

The data set used for this study contained aerial imagery publicly available through the Hazards Data Distribution System (HDDS), provided by the U.S. Geological Survey (Hazards Data Distribution System Explorer 2016). In particular, aerial imagery captured by Civil Air Patrol during the Colorado Floods that took place in 2013 was chosen to be rated by participants of the study.

Participants were asked to rate up to 250 images randomly chosen from the Colorado floods data set. They were presented with a simple interface, containing an image, the question "Do you see any damage?" and buttons for three possible answers, "Yes", "Maybe", and "No". They were also provided with a reminder of the instructions, "This set contains 250 subtasks. *[Conditional instructions.]*". The layout of the image rating page can be seen in Figure 1.

EXPERIMENT DESIGN

We carried out a 3x2 between subjects experiment design, using the following factors and levels.

- Amount of `required work`:
  - `0+`: Participants could rate as many images as they wanted (even none) and finish rating at any time by proceeding to the survey. This examined requiring no work.
    - The *conditional instructions* were: "**You may complete any number of subtasks before clicking the "Go to Survey" button to finish.**"
    - The "Go to Survey" button was always present.
  - `1+`: Participants had to rate at least one image before proceeding to the survey. This examined requiring the smallest amount of work possible, to see if this would crowd-out motivation.
    - The *conditional instructions* were: "**You must complete at least 1 subtask before clicking the "Go to Survey" button to finish.**"
    - The "Go to Survey" button appeared after 1 image was rated.
  - `10+`: Participants had to rate at least 10 images before proceeding to the survey. This examined requiring an order of magnitude more more work than 1+, but still a relatively small amount.
    - The *conditional instructions* were: "**You must complete at least 10 subtasks before clicking the "Go to Survey" button to finish.**"
    - The "Go to Survey" button appeared after 10 images were rated.

Variable	Description
Image Count	The total number of images rated.
Extra Image Count	The number of images rated beyond those required.
Total Time	Total time spent rating images, in seconds; the time between seeing the first image and moving on to the survey. We identified and excluded breaks of more than 5 minutes when rating an image.
More than Required	Whether the worker rated more images than the required amount.
Finished	Whether the worker rated the whole set.
Abandoned	Whether the worker accepted the HIT but abandoned it before completing the survey. Note that for this variable, all workers who accepted the HIT were included.
Agreement	Agreement with consensus. As ground truth ratings for the images were not previously known, we calculated agreement as the percentage of images for which a worker selected the consensus rating.

Table 2. Summary of the *performance* variables, based on workers' performance during the rating part of task.

Variable	Description
Checked-Understand	Whether the "I did not understand the instructions" box was checked.
Checked-Paid-More	Whether the "I thought I would get paid more" box was checked.
Checked-Rejected	Whether the "I thought my submission would not get approved" box was checked.

Table 3. Summary of the *survey checkbox* variables, based on workers' selection of the survey checkboxes.

- Presence of `progress feedback`:
  - `N`: No feedback on the current progress of ratings provided was present.
    - No information about the number of images rated was shown.
  - `P`: Feedback was given to the participants in the form of progress counts, showing how many images they have rated, as well as how many ratings were required (if any) and the total size of the set. As a design decision for simplicity in potentially showing progress towards two targets (completing required work and completing the entire set), we showed a textual representation of progress count rather than a graphical bar.
    - The text "**Progress: *L* / 250**" was shown.
    - The text "Required: *L* / *R*" was shown until the "Go to Survey" button appeared.

  (Where *L* is the number of images rated and *R* is the number of ratings required to go to the survey.)

Other than the variations described here, workers received identical tasks. This resulted in 6 conditions, which we refer to using `0+N`, `1+N`, `10+N`, `0+P`, `1+P`, `10+P`. Screenshots demonstrating the differences in conditions can be seen in Figure 3.

RESULTS AND ANALYSIS

We recruited 602 MTurk workers who completed the HIT, with an additional 61 workers who started—but did not complete—the HIT. Workers were assigned randomly into the 6 conditions. Workers were paid a flat rate of 50¢ if they completed the survey, regardless of the amount of work they did beyond the required limit.

Our analysis focused on three types of variables: *performance*, *survey checkbox*, and *survey free-response* variables. Performance variables were based on worker actions logged during the image rating portion of the HIT. Survey free-response variables consist of categories—identified using an open coding scheme as discussed below—from the free-response motivation question, treating each category as a separate Boolean variable. Survey checkbox variables are also treated as separate Boolean variables. A summary of all variables and their definitions is given in Tables 2, 3 and 4.

To analyze workers' responses to the free-response survey question, an open coding approach was followed. We began with the pre-defined categories *N/A*, *UNDERSTAND*, *PAID-MORE*, and *REJECTED*, to cover unrelated responses and loosely correspond to the options in the checkbox question. Two annotators where tasked with independently going over a sample of the submitted responses (the first 100) and identifying main categories. The two independent sets of categories were then used as a basis for a common coding scheme for the whole set of workers'

Variable/Category	Guideline	Example Response
DISASTER	Were interested in disasters.	*"Live in tornado alley. Interesting to see if anything looked like tornado damage."*
DO-MORE	Wanted to do as much as possible or finish the whole set. Also wanted to be thorough or do more than expected.	*"Wanted to finish the whole thing"*
ENJOY	Enjoyed the task, found it interesting and fun.	*"It was fun and interesting."*
EXTERNAL	Mentioned external obligations that did not allow them to continue, such as going to work.	*"Short on time and had to get to work."*
FEELING	Felt that what they did was the right amount or, wanted to do a certain number or, felt ready to move on to survey.	*"I thought I had reached 50 images submitted."*
HELP	Wanted to help the project.	*"I tried to complete as many as possible to contribute to the study."*
INSTRUCT	Said they did what the instructions said or the minimum.	*"because it asked to do at least 10 images"*
LOST-INTEREST	Mentioned getting bored or the task was becoming repetitive.	*"Was enjoying the task and stopped when it became monotonous"*
LOST-TRACK	Lost count of how many images they had rated or forgot to go to the survey.	*"wasn't thinking of the amount until I saw the survey button"*
PAID-MORE	Thought they would get paid more.	*"I completed 10 tasks looking for a bonus."*
REJECTED	Thought their submission would get rejected or not approved, wanted to make sure they got paid.	*"I tried to complete enough images to ensure i will get paid"*
SEE-MORE	Wanted to see more images.	*"Wanted to look at more"*
SKILL	Wanted to get better at the task, or thought they were good at it. Also concerned about accuracy of their work.	*"I felt that I got the general gist of the types of imagery I would see."*
TECH	Mentioned technical reasons.	*"I completed the number of images I did because the software had a slight delay for each image that was loaded."*
UNDERSTAND	Didn't understand the instructions or how many they were supposed to do. Thought the instructions were unclear.	*"I was unclear if I needed to do them all or if just by looking at one I could go on to the survey."*
VALUE	Considered the amount they did appropriate for payment, wanted to do enough work for how much they were getting paid.	*"Well honestly as much as I enjoy aerial images and high res airborne imagery there is only a certain amount of time I'm going to spend for $0.50."*
OTHER	Other reasons.	*"Because I felt the survey would be indepth and the focus of this HIT."*
N/A	Blank responses, numbers, not addressing the question.	*"Observed"*

Table 4. Summary of the categories for workers' text responses, along with exemplar responses, as a result of applying an open coding scheme. Each category also corresponds to a *survey free-response* variable.

responses. The responses were then again independently categorized, based on the agreed categories—during this second pass, the *DO-MORE* category was introduced. The final categorization was produced after the resolution of disagreements. The annotators remained the same throughout the various stages of the process. Inter-annotator agreement before resolution was measured using Cohen's kappa coefficient, with a resulting $\kappa = 0.67$, which is described by Landis and Koch (1977) as "substantial" agreement and Fleiss et al. (2013) as "fair to good" agreement. In total, 18 different categories were identified, which are summarized in Table 4.

For our statistical analysis, we performed omnibus tests for each variable to identify significant differences in `required work` and `progress feedback`, and identify possible interactions. For significant omnibus tests, we followed with post-hoc pairwise tests. As numerical variables were not normally distributed (determined using a Shapiro-Wilk test), we used Aligned Rank Transform (ART) for omnibus tests, the Wilcoxon rank-sum test for post-hoc tests, rank-biserial correlation (r) to compute effect sizes, and we report medians. ART (Wobbrock et al. 2011) is nonparametric and suitable for handling multiple factors and also allows us to analyze interaction effects. The ART procedure transforms data so that a factorial ANOVA can be applied. With Boolean variables, we used logistic regression for omnibus tests, Pearson's chi-squared test for post-hoc tests, phi (ϕ) to compute effect sizes, and we report percentages.

If no interaction was present in the omnibus test, with post-hoc tests we tested main effects present for `required work` (i.e. `0+ ~ 1+`, `0+ ~ 10+` and `1+ ~ 10+`) with a Bonferonni correction of 3 and `progress feedback` (i.e. `N ~ P`) with no correction. If an interaction was present, we performed post-hoc tests both within each feedback

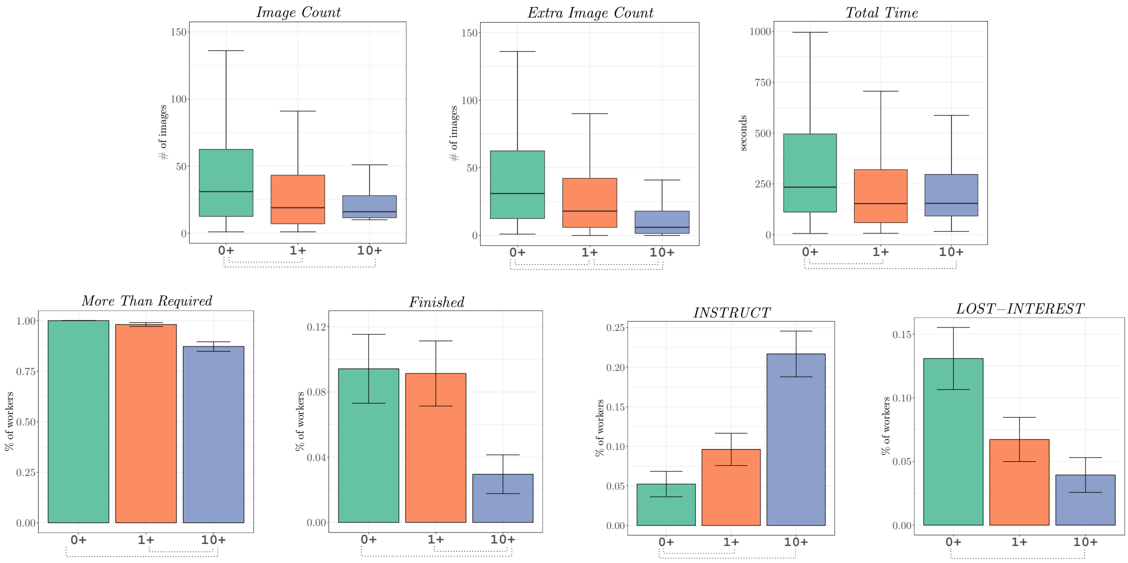


Figure 4. Summary plots of statistically significant post-hoc comparisons for `required work` main effects. For numerical variables, 25th, 50th (median) and 75th percentiles are shown, along with minimum and maximum values (whiskers), excluding outliers. For Boolean variables, percentages along with standard error bars are shown. Dashed lines indicate significant comparisons.

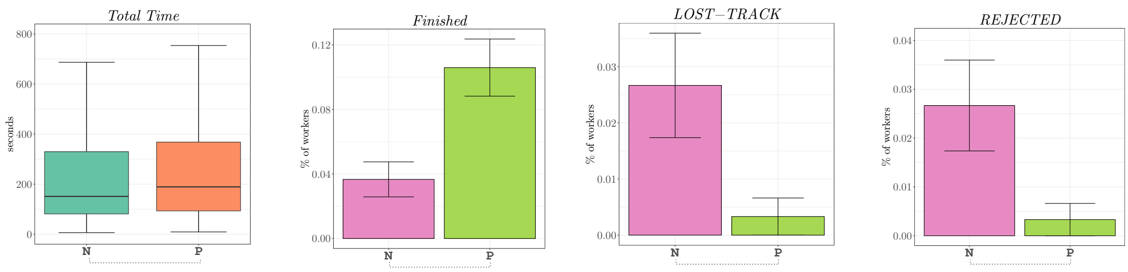


Figure 5. Summary plots of statistically significant post-hoc comparisons for `progress feedback` main effects. For numerical variables, 25th, 50th (median) and 75th percentiles are shown, along with minimum and maximum values (whiskers), excluding outliers. For Boolean variables, percentages along with standard error bars are shown. Dashed lines indicate significant comparisons.

condition and between (i.e., 0+N ~ 1+N, 0+N ~ 10+N, 1+N ~ 10+N, 0+P ~ 1+P, 0+P ~ 10+P, 1+P ~ 10+P 0+N ~ 0+P, 1+N ~ 1+P and 10+N ~ 10+P) with a Bonferonni correction of 9.

Tables 5, 6 and 7, along with Figures 4 and 5 contain a summary of the variables that were found to have statistically significant differences. As the post-hoc comparisons of interactions for *Checked-Paid-More* were not significant, we omit their inclusion from some summary figures and tables. We observed no significant variations among conditions in the *Agreement* variable (86.6% overall) and the *Abandoned* variable (9.2% overall) and therefore, we have omitted them from further analysis.

The vast majority of workers did at least some more work than was required: 572, or 95.0%, of workers, across all conditions, provided additional ratings. The number of ratings provided increased when no specific amount was required, versus requiring a small amount; the median amount of ratings offered in the 0+ conditions was 31, when compared to 19 for the 1+ conditions ($p < .001$). Moreover, the presence of feedback in the form of progress counts resulted in more workers completing the entire set. We observed significantly more people finishing the set in the P conditions (10.6%) than in the N conditions (3.7%, $p = .02$) Worker retention was the highest in cases with progress counts, with 10.6% of workers in the conditions with progress feedback finishing the entire set of 250 images. Requiring a small amount of work led to a sharp drop in continuing workers, for example, shortly after the lower bound of 10 images was reached. This can be seen in the chart of worker retention presented in Figure 6a.

Based on the survey results, workers whose responses indicated a loss of interest (*LOST-INTEREST*) were significantly more in the 0+ conditions, as compared to the 10+ conditions. This indication of interest points to

Variable	RWrk	Fdbk	RWrk × Fdbk	0+N	1+N	10+N	0+P	1+P	10+P
Workers				90	108	102	101	100	101
Image Count	$p < .001$			29	15	17	33	21	15
Extra Image Count	$p < .001$			29	14	7	33	29	5
Total Time	$p < .001$	$p = .011$		201s	127s	148s	252s	188s	156s
More than Required	$p < .001$			100.0%	96.3%	85.3%	100.0%	100.0%	89.1%
Finished	$p = .001$	$p < .001$		4.4%	5.6%	0.9%	13.9%	13.0%	4.9%
Checked-Paid-More			$p = .04$	23.3%	26.0%	13.7%	13.9%	27.0%	23.8%
INSTRUCT	$p < .001$			6.7%	9.3%	19.6%	3.9%	10.0%	23.8%
LOST-INTEREST	$p = .002$			15.6%	9.3%	4.9%	10.9%	4.0%	2.9%
LOST-TRACK		$p = .011$		1.1%	2.8%	3.9%	0.9%	0.0%	0.0%
REJECTED		$p = .011$		1.1%	5.6%	0.9%	0.9%	0.0%	0.0%

Table 5. Summary of results for variables with statistically significant differences from omnibus tests. Values are based on workers who completed the HIT; worker counts for each condition are given in the top row). Numerical variables are given as medians and Boolean variables as percentages. Numerical variables were tested with the Aligned Rank Transform and Boolean variables with logistic regression.

workers being more motivated by their own intrinsic motivation—up to the point where they decided to finish the task—when no work was required. We observed a high proportion of workers reporting that the primary reason for their performance was a result of following the instructions (*INSTRUCT*) in the 10+ conditions, in particular, 21.7% of workers. This was significantly higher than in the 0+ and 1+ conditions. This may indicate that, when more work was required, workers were motivated more by simply complying with the instructions to receive their extrinsic reward payment.

Levels of *LOST-TRACK* and *REJECTED* category were low across all conditions. However, we found both to be significantly lower in the P conditions, indicating that the progress bar may have given workers some additional clarity on how they were performing.

Looking at responses to the checkbox survey question, we found no significant differences in the post-hoc tests, indicating that among conditions, workers had a similar level of understanding of the instructions and payment scheme. Across all conditions, 9.2% of workers *Abandoned* the HIT (relative to all who initially accepted it), which was not significantly different between conditions. Results also indicate a high percentage of *Agreement*, 86.6% overall, which did not significantly vary between conditions. Thus we did not see an indication that worker accuracy was affected.

We did observe some minor confusion regarding instructions (*UNDERSTAND*, 3.9% of free responses) and payment (*PAID-MORE*, 0.2% of free responses). However, these were not different across conditions. *Checked-Paid-More* was found to have a significant interaction in the omnibus test, but not in the post-hoc tests.

Regarding our research questions, in the context of paid crowdsourcing for disaster response in an image rating task:

RQ1: What is the impact of requiring work versus not requiring work?
⋄ *When less work was required, workers did more work, were more likely to indicate stopping due to a loss of interest, and were less likely to indicate stopping due to the instructions.*

Workers in the 0+ conditions did significantly more work beyond their requirements than the 1+ and 10+ conditions (*Extra Image Count*), and overall provided significantly more ratings (*Image Count*), and spent more time on the work (*Total Time*). On the contrary, workers in the 10+ conditions were significantly less likely to provide more work than required than workers in lower requirement conditions (*More than Required*), as well as less likely to complete the entire set (*Finished*).

Requiring work also impacted self-reported worker motivation. Analyzing workers' reported motivations for their performance, we observed that workers in the 10+ conditions were more likely to report complying with instructions as the primary reason for providing the amount of ratings they did, with 21.7% of the responses in these conditions belonging to the *INSTRUCT* category. In contrast, workers in the 0+ conditions were more likely to express interest up to the point when they decided to finish the task, with 13.1% of the responses in these conditions belonging to

Variable	`0+` ~ `1+`	`0+` ~ `10+`	`1+` ~ `10+`
Image Count	31 ~ 19 $p < .001, r = 0.23$	31 ~ 16 $p < .001, r = 0.25$	
Extra Image Count	31 ~ 18 $p < .001, r = 0.27$	31 ~ 6 $p < .001, r = 0.56$	18 ~ 6 $p < .001, r = 0.33$
Total Time	234s ~ 153s $p = .002, r = 0.20$	234s ~ 154s $p = .005, r = 0.18$	
More than Required		100.0% ~ 87.2% $p < .001, \phi = 0.25$	98.1% ~ 87.2% $p < .001, \phi = 0.20$
Finished		9.4% ~ 3.0% $p = .04, \phi = 0.13$	9.1% ~ 3.0% $p = .047, \phi = 0.12$
INSTRUCT		5.2% ~ 21.7% $p < .001, \phi = 0.23$	9.6% ~ 21.7% $p = .004, \phi = 0.16$
LOST-INTEREST		13.1% ~ 3.9% $p = .006, \phi = 0.16$	

Table 6. Summary of statistically significant post-hoc comparisons for `required work` main effects. *Finished* had no such comparisons. Numerical variables are given as medians and Boolean variables as percentages. Numerical variables were tested with the Wilcoxon rank-sum test and Boolean variables with the chi-squared test, applying the Bonferroni correction.

Variable	`N` ~ `P`
Total Time	151s ~ 189s $p = .019, r = 0.11$
Finished	3.7% ~ 10.6% $p = .020, \phi = 0.13$
LOST-TRACK	2.7% ~ 0.3% $p = .043, \phi = 0.18$
REJECTED	2.7% ~ 0.3% $p = .043, \phi = 0.18$

Table 7. Summary of statistically significant post-hoc comparisons for `progress feedback` main effects. *Total Time* had no such comparisons. Numerical variables are given as medians and Boolean variables as percentages. Numerical variables were tested with the Wilcoxon rank-sum test and Boolean variables with the chi-squared test, applying the Bonferroni correction.

the *LOST-INTEREST* category. Compared with the previous quantitative measures, these results lend support to the presence of the motivation *crowding-out* effect.

RQ2: What is the impact of providing feedback on progress?
⋄ *Providing progress feedback resulted in more work done and improved perceived clarity of the task.*

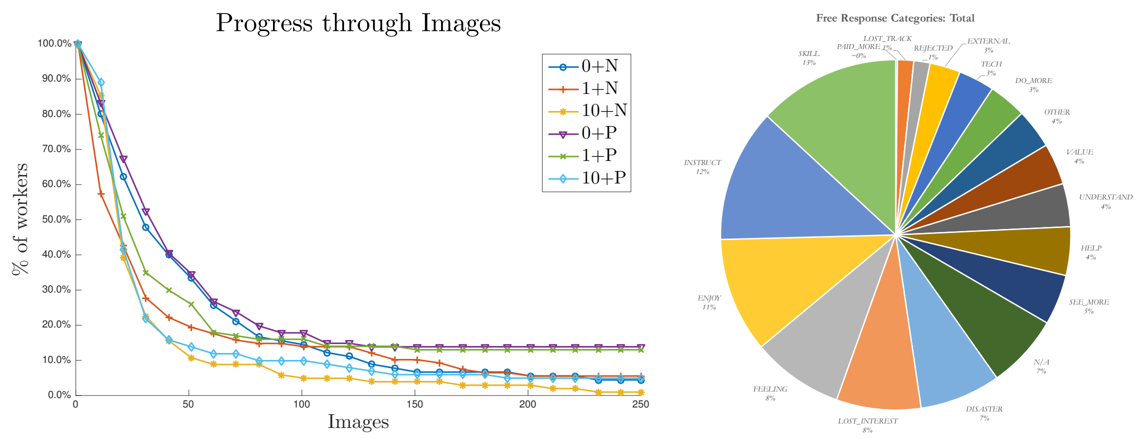
Workers in conditions with progress feedback were significantly more likely to complete the entire image set of 250 images (*Finished*), as well as spend more time on the task (*Total Time*). These results indicate that providing progress feedback increased worker engagement in the task.

Giving workers progress feedback also reduced the amount of losing track of what they had done (*LOST-TRACK*) and fear of work being rejected (*REJECTED*).

RQ3: What different motivations do workers provide for their contributions in the project?
⋄ *Workers provided a variety of motivations other than payment for their participation.*

Our open coding approach revealed a variety of different motivations for workers performing beyond their requirements. Figure 6b depicts the breakdown of categories in responses to the first survey question.

The task was well received by workers, with 10.7% of the workers' free-response answers falling into the *ENJOY* category and another 4.5% clearly stating wanting to help the project as a primary reason for rating more images. Another 8.5% of workers reported that they felt the amount they had reached was adequate to their opinion and felt ready to finish the HIT (*FEELING*). The above responses indicate intrinsic motivations regarding the worker's



(a) (b)

Figure 6. (a) Worker retention chart by image count. The x-axis shows the image count and the y-axis shows the percentage of workers in a condition that rated at least that many images. The rapid falloff after completing work in the 10+ conditions, and the large percentage of workers in the 0+P and 1+P conditions who competed all available images, can be clearly seen. (b) Breakdown of response categories for responses to the free-response motivational survey question.

personality and abilities. We also identified another motivation for workers, which has to do with the nature of the task, as 7.5% of responses fell into the *DISASTER* category. This group of workers were interested in analyzing disasters.

Notably, there were still some responses indicating potential misinterpretation of the instructions, including workers concerned about their work being rejected, even though we explicitly stated work would not be rejected, or expecting more payment for more work even though none was offered. This may be due to worker expectation based on the MTurk platform. This would indicate that clarity of instructions and setting clear expectations is of great importance.

CONCLUSION AND FUTURE WORK

In this work, we invited MTurk workers to participate in a disaster response scenario by asking them to provide ratings for images taken during the Colorado floods of 2013. We awarded a fixed amount of payment and varied the minimum amount of ratings required as well as whether or not progress feedback was provided. Our results indicate that most of the workers did more work than required to receive payment. We also observed that workers generally did more work due to their own interest when no minimum work requirement was asked of them.

Existing literature points to many other possible payment schemes, such as payment per unit of work completed, as well as bonuses per goal accomplished (Ho et al. 2015). Future work could compare these per-unit schemes to a required work scheme. Moreover, we explored 3 different levels of required work for the purposes of this study, with 10 images being the highest amount. We would like to examine the effects of requiring even larger amounts of work in participation and engagement in disaster response crowdsourcing.

One interpretation of giving workers flexibility in the amount of work they do is that it effectively allows them to set their own wage. In a survey of workers performed by Munro et al. (2013), they found a suggested wage of 0.1¢ to 2¢ per "judgment". In our work, we found that the effective wage in the 0+ conditions came to 0.9¢ per rating on average, which falls into that range (in contrast with the higher per-rating wages of 1.1¢ in the 1+ and 1.5¢ in the 10+ conditions.

Making crowdsourced tasks more interesting and engaging is a promising area for future exploration. In this work, we found that workers were more likely to indicate reasons related to interest for their participation when no work was required of them. Therefore, we believe that designing tasks that are more engaging and interesting for participants will have a bigger impact if a payment model is chosen where no work is required. This work is part of an initial effort into creating a platform that can be used to develop techniques for improving the experience of contributing to crowdsourced disaster response—for both paid crowd workers and volunteers.

ACKNOWLEDGMENTS

This work was supported by a Northeastern University TIER 1 grant, Google, and the New World Foundation in collaboration with Public Lab. We would like to thank the Civil Air Patrol and the U.S. Geological Survey for making the images available and the Mechanical Turk workers for their participation.

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On Variety, Complexity, and Engagement in Crowdsourced Disaster Response Tasks

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ABSTRACT

Crowdsourcing is used to enlist workers as a resource for a variety of applications, including disaster response. However, simple tasks such as image labeling often feel monotonous and lead to worker disengagement. This provides a challenge for designing successful crowdsourcing systems. Existing research in the design of work indicates that task variety is a key factor in worker motivation. Therefore, we asked Amazon Mechanical Turk workers to complete a series of disaster response related subtasks, consisting of either image labeling or locating photographed areas on a map. We varied the frequency at which workers encountered the different subtask types, and found that switching subtask type at different frequencies impacted measures of worker engagement. This indicates that a certain amount of variety in subtasks may engage crowdsourcing workers better than uniform subtask types.

Keywords

crowdsourcing, Amazon Mechanical Turk, variety, complexity, engagement

INTRODUCTION

Crowdsourcing, in both paid and volunteer contexts, is an increasingly popular approach to acquiring and applying human skills for a wide variety of applications (Rouse 2010; Geiger et al. 2011; Schenk and Guittard 2011). Crowdsourcing is emerging as a promising method to involve the general public in disaster response. This lends itself to a variety of perspectives, such as studying social and organizational aspects of successful crowdsourced disaster response projects (Liu 2014; Goodchild and Glennon 2010; Crowley 2013) and examining the multitude of technical aspects related to crowdsourced disaster response (Imran et al. 2014; Lue et al. 2014), including crowdsourced processing of aerial imagery (Ofli et al. 2016; Munro et al. 2013).

To this end, various efforts have been established, with the main goal of exploring ways of involving the crowd in disaster response. Of particular relevance to our work is Public Lab, a community dedicated to developing open source hardware and software tools for collecting and analyzing data from environmental concerns, including disasters. One such tool was MapMill, developed by Public Lab and Jeff Warren, which was used for crowdsourced analysis of aerial images taken from the Gulf Coast after the Deepwater Horizon oil spill. MapMill was subsequently adapted for analysis of aerial images from Hurricane Sandy, taken by the Civil Air Patrol, in 2012 in a collaboration between the Humanitarian OpenStreetMap Team and FEMA (Munro et al. 2013). Volunteered data from MapMill were used to create a heatmap of the affected area, with applications for directing resources to areas with the highest damage reports (Meier 2012).

While both Hurricane Sandy and the Deepwater Horizon oil spill were large-scale events which attracted many volunteers and resources, this is not always the case for incidents in disaster response. Munro et al. (2013) pointed out the difficulty in recruiting volunteers for events with lesser magnitude, impact, and/or public outreach and suggested paid crowdsourcing as a cost-effective alternative. However, engaging paid workers or volunteers is key. In volunteer settings, it is known that most participants are only engaged for a short time and much of the work is accomplished by a small portion of people (Sauermann and Franzoni 2015; Sturn et al. 2015). In paid settings,

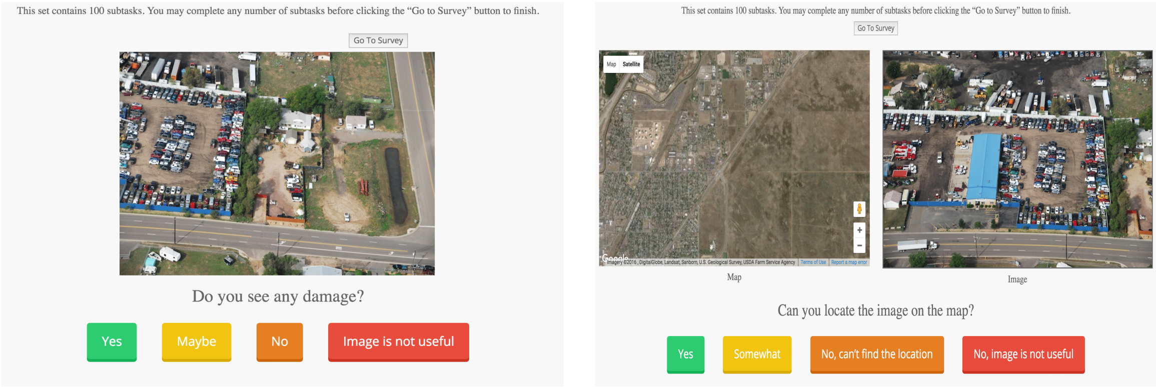

Figure 1. Example screenshots of the label (left) and map (right) subtasks.

worker motivations beyond simple payment are present (Kaufmann et al. 2011), and crowdsourcing marketplaces such as Amazon Mechanical Turk (MTurk) mean that another, more interesting task is only a click away.

As techniques for improving worker engagement and motivation in crowdsourced tasks are of interest, in this work, we explored the use of *variety* to improve crowdsourcing worker engagement in disaster response tasks. We focus primarily on *behavioral engagement*—that is, the observable persistence and effort one puts toward a task (Reeve 2015). We consider crowdsourcing tasks which can be broken down into a sequence of smaller subtasks, in which once one subtask is completed, the next subtask is served to the worker; this is a common workflow structure used in crowdsourcing. Thus, we use the term *subtask* to refer to one of these smaller, indivisible units of work, and *task* to refer to the overall sequence of subtasks served to a crowdsourcing worker.

We developed a task where workers were invited to complete a sequence of image related subtasks, specifically, *label subtasks*, a simple subtask where workers selected a label for an image from a set, and *map subtasks*, a more complex subtask where workers were asked to locate an image on a map and indicate if they were successful. When considering the *task complexity* (Wood 1986) of the subtasks, we view the map subtask as more complex as it contains, for example, both more "information cues" (the image and the map) and "required acts" (navigating the map and indicating success).

We posted a Human Intelligence Task (HIT) on MTurk that paid workers a fixed amount to complete any number of subtasks, with no minimum amount of work required, and answer a post-survey about their experience. We considered the baseline task to be a sequence of only label subtasks, similar to what a worker would encounter in MapMill. To examine the effects of variety—in terms of subtasks with different complexity—on performance, we varied the frequency with which the more complex map subtasks were served to workers during their progress through completing label subtasks. We wished to explore what impact, if any, differing schedules of task variety in our design would have on worker performance, including levels of engagement and output quality.

We found that when inserting map subtasks into a sequence of label subtasks at fixed intervals, certain intervals resulted in increased engagement—measured as voluntary time contributed to the task—compared to workers who only received label subtasks. In contrast, using only of one type of subtask—either maps or labels—did not lead to increased engagement when comparing one subtype to the other. Furthermore, introducing switches between the two different types of subtasks with related content did not observably affect workers' quality and speed on the label subtasks. We believe these findings indicate that tasks consisting of simple subtasks sequences can be made more engaging for workers by inserting more complex subtasks at appropriate intervals, without impacting quality. This work contributes to the growing literature on worker engagement in the design of crowdsourcing systems, by providing useful insights to worker performance in different settings of variety and complexity.

In the sections that follow, we start by presenting an overview of the related work that can be found in the present literature. We continue with providing a description of the task and experiment design. We then summarize our results analysis and conclude with some points of discussion.

RELATED WORK

In the past, there have been various efforts in involving volunteers in disaster response through crowdsourcing. Immediately after the Haiti earthquake of 2010, the Ushahidi project was established as a means of analyzing messages sent during the disaster and geolocating incidents in real-time (Liu 2014). Tomnod (Barrington et al.

2012) also invited volunteers to identify damage on buildings using post-earthquake satellite and aerial imagery of the Port-au-Prince area of Haiti. Volunteered geographic information has also been analyzed after the wildfires in Santa Barbara between 2007 and 2009 (Goodchild and Glennon 2010). Kerle et al. (Kerle and Hoffman 2013) addressed challenges that arise when designing a crowdsourcing task for disaster response, such as providing clear instructions that will ensure that volunteers will comprehend the task correctly and produce valid results, as well as generating useful maps for responders from the merged results. However, none of the above focused on exploring elements of task design to increase engagement.

Variety has long been recognized as a key factor in creating motivating work. Hackman and Oldham (1976) designed and tested a Job Characteristics Model, aiming to increase internal motivation and performance of employees through effective job design. They identified five core job characteristics, which include skill variety, along with task identity, task significance, autonomy, and job feedback. Lunenburg (2011) followed that work, providing an overview of empirical studies on the Job Characteristics Model, as well as applications of the model in the field of management. Other research has examined the tradeoffs between variety and specialization in work. Staats and Gino (2012) found that when examining the repetitive tasks of bank workers, specialization improved productivity over short periods of time (i.e., a day), while over longer periods, variety did. Narayanan et al. (2009) found that for software maintenance, a balance between specialization and variety led to the highest productivity.

In the crowdsourcing domain, Kittur et al. (2013), in their framework for future crowd work, proposed job design to support both organizational performance, but also worker satisfaction. Feedback from workers suggests that motivation is negatively impacted by monotonous tasks. Recent work has demonstrated that the ordering and continuity of crowdsourced microtasks can impact worker performance and engagement (Lasecki et al. 2014; Cai et al. 2016).

In work closely related to ours, Lasecki et al. (2015) examined the effects of contextual interruptions on crowdsourced microtasks (i.e. subtasks), where workers would switch between tasks of landmark locating on a map and image labeling. Their findings showed that switching context between closely related subtasks could slow workers down, but did not examine effects on workers' engagement. Dai et al. (2015) found that inserting short "micro-diversions" (such as pages of a graphic novel) into subtask sequences could improve worker engagement. However, these diversions did not result in work being completed. We see our work as a kind of combination of these two approaches: looking towards improving worker engagement through "diversions" that are different types of subtasks. Our work further explores the tradeoffs of various rates of interleaving different types of subtasks.

While we are primarily interested in worker engagement through variety, a wide body of approaches to improving crowdsourcing have been explored, including game mechanics (von Ahn and Dabbish 2004; Sturn et al. 2015), understanding payment schemes (Mason and Watts 2009; Gao and Parameswaran 2014; Acar and Ende 2011) and optimizing microtask workflows to reduce the amount of work needed to be done (Yan et al. 2011; Laws et al. 2011; Dai et al. 2010).

In this work, we used the total time workers spent voluntarily completing subtasks as an indication of engagement. When measuring engagement, a body of work related to ours has examined total time spent on task as a valid metric of engagement. In work by Khajah et al. (2016), MTurk was used to study "voluntary time on activity" as engagement. Participants were paid to try a game for several minutes, after which they could quit or continue to play voluntarily with no further compensation. Additional work has used time or "subtask" counts to operationalize engagement (Kassinove and Schare 2001; Andersen et al. 2011; D. Lomas et al. 2013; J. D. Lomas et al. 2016). In our work, workers were not required to spend any minimum time on the task or complete any minimum number of subtasks, as the setup allowed them to stop at any time, complete the survey questions, and get paid. Thus, we consider any time spent working on the task as voluntary and therefore a measure of engagement.

STUDY DESCRIPTION

Task Design

The subtasks we designed were inspired by the crowdsourced disaster response platform MapMill, where volunteers were asked to assess images from the Deepwater Horizon oil spill and Hurricane Sandy. Thus, our subtasks mainly involved viewing an aerial image and answering a question about the image by choosing from a small predefined set of answers. For this work we used a publicly available data set of Civil Air Patrol's aerial images of the 2013 Colorado floods, provided by the U.S. Geological Survey's Hazards Data Distribution System (2016), although workers were not informed of the source of the images. The two subtasks were the following:

- *Label subtasks*: Participants were presented with an image and were asked to answer a damage related question, with predefined answers. They were presented with a simple interface, containing an image, a question and buttons for four possible answers. The question chosen was *"Do you see any damage?"* and the

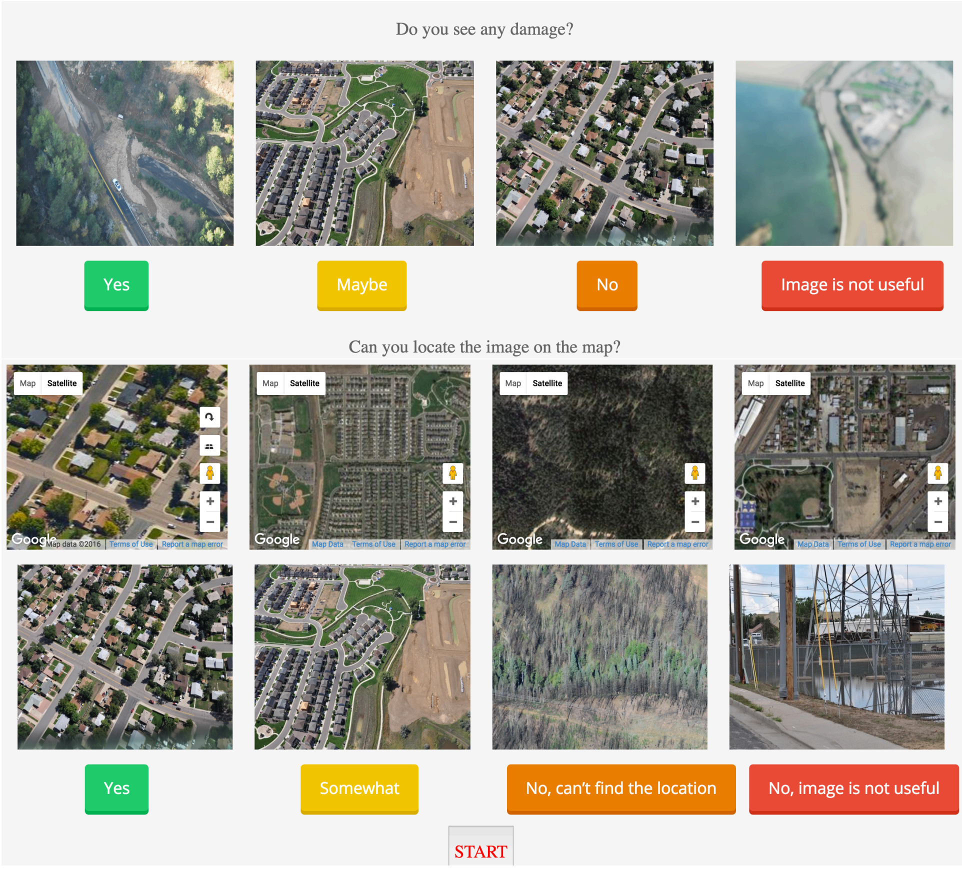

Figure 2. Example of the training provided to workers for our task.

possible answers were *"Yes"*, *"Maybe"*, *"No"* and *"Image is not useful"*. An example is shown in Figure 1 (left). We considered this to be a simple subtask; from a disaster response perspective, this type of subtask could be useful in locating areas of damage.

- *Map subtasks*: Alongside an image, participants had access to a map. provided by Google Maps (2016), and were asked to locate the image in the map view. Participants could pan and zoom on the map; the image's embedded GPS coordinates were used for the initial map location. The question chosen was *"Can you locate the image on the map?"* and the possible answers were *"Yes"*, *"Somewhat"*, *"No, can't find the location"* and *"No, Image is not useful"*. An example is shown in Figure 1 (right). We considered this to be a more complex subtask; from a disaster response perspective, this type of subtask could be useful for confirming and improving the locations of images.

Experiment Design

We ran a HIT on MTurk to recruit participants to complete subtasks. We chose MTurk for participant recruitment as it remains one of the most popular crowdsourcing marketplaces, is widely used in crowdsourcing research, and has a ready pool of participants who can be rapidly recruited. Additionally, MTurk workers have been shown to behave similarly to "traditional" subject pools (Paolacci et al. 2010) and to be motivated by more than payment (Mason and Watts 2009; Kaufmann et al. 2011; Chandler and Kapelner 2013). IRB approval was received for the purposes of the study. The HIT paid 50¢. The HIT title, which informed workers that they would be doing work related to disasters, was:

> Disaster Area Map Image Tasks

The HIT description was:

> Perform image related subtasks such as image labeling and image locating on a map and answer a short survey on the task.

The HIT keywords were:

> image, locate, locating, center, map, labeling, label

Upon accepting the HIT, workers were informed they were participating in a study and required to consent to proceed. Workers were then provided with the following general instructions:

> Click **START** to begin completing a series of image related tasks. For each image, answer the question that appears beneath the image. Some tasks require locating the images on the right on the map on the left. You may move around, zoom and, if available, rotate the map view, using the corresponding map controls. Try to center the map on the location shown in the image, making the map look as much like the image as possible. Please do not use your browser's back button while locating or taking the survey. This HIT requires Javascript. When you are finished, click the "Go To Survey" button to complete a short survey, after which your HIT will be completed. **This set contains 100 subtasks. You may complete any number of subtasks before clicking the "Go to Survey" button to finish. If you complete the survey, your submission will be approved.**

Motivated by the work of Ho et al. (2015), to mitigate effects of different beliefs workers may bring about the amount of work required to be approved, the instructions explicitly state submissions will be approved if the survey is completed.

After an example for the types of subtasks, which acted as a small tutorial (shown in Figure 2), workers then proceeded to complete subtasks by answering the questions that accompanied the images. In our HIT, workers were allowed to complete *up to* 100 subtasks.

At any point, participants could either continue completing subtasks or choose to complete the HIT by answering a short survey. If a worker completed all possible subtasks, they were automatically taken to the survey. In the survey, participants were asked to provide some feedback about the reasons that led them to their performance, in the form of a multiple selection question. The survey asked workers, *"Can you tell us why did you complete the number of subtasks that you did? Check all that apply."* Workers could check any number of the following checkboxes: *"I was engaged in the task," "I thought my submission would not get approved," "I wanted to help the project," "I did not understand the instructions," "I had no indication to stop," "I thought the payment was worth that much work," "I thought I would get paid more," "I wanted to see more images,"* and *"Other"*.

While there was a maximum of 100 subtasks available, workers were able to finish working on the subtasks at any time without penalty. Workers would be paid the fixed reward for completing the HIT, regardless of the number of subtasks completed—even if they completed no work at all—so we consider the work done and time spent on it essentially voluntary. Thus we believe examining work done and time spent are reasonable measures of *behavioral* engagement, as workers can, at any time, finish the HIT by going to the survey to collect their payment and move on to another HIT they feel is more worthwhile. As discussed in the related work, other work has used measures of time to examine engagement on MTurk.

We carried out a between subjects experiment design, recruiting 720 workers who completed the HIT, with an additional 133 workers who started, but did not complete, the HIT. Workers were randomly assigned into one of 6 conditions with different proportions of subtasks. In the `AllL` and `AllM` *uniform conditions*, workers were served all label or all map subtasks, respectively. In the `4L:1M`, `9L:1M`, `19L:1M`, and `29L:1M` *variety conditions*, workers were served one map subtask at a regular interval of label subtasks (e.g., in `4L:1M` one map subtask was served after every 4 label subtasks). As workers were randomly assigned into a condition, they did not have any control over the type of subtasks they were given. The images used in the subtasks were randomly ordered for each subject. Aside from the different proportions of subtask types, all workers received exactly the same HIT. For example, workers would receive the example map subtask tutorial screen even if they were not served any actual map subtasks. MTurk did not allow participants to participate in the study more than once, which ensures that our data does not contain duplicate entries for workers.

RESULTS

Data Analysis

We analyzed the following variables of worker performance on the subtasks:

- *Subtask Count*: The total number of subtasks, both label and map type, completed.
- *Label Count*: The total number of label type subtasks completed.
- *Subtask Agreement*: The percentage of all types of subtasks, both label and map, whose answers agree with the consensus answer. As we do not have ground truth for our subtasks, we use the consensus answer as the "correct" response. This was simply the answer selected by the majority of workers. We use agreement to evaluate worker accuracy.
- *Label Agreement*: The percentage of label type subtasks whose answers agree with the consensus answer, used as ground truth.

Variable	`AllL` ~ `AllM`	`AllL` ~ `4L:1M`	`AllL` ~ `9L:1M`	`AllL` ~ `19L:1M`	`AllL` ~ `29L:1M`
Subtask Count $p < .001$	**20 ~ 6** $p < .001, r = 0.55$	*20 ~ 15* $p = .052, r = 0.18$	20 ~ 22	20 ~ 17	20 ~ 20
Label Count $p < .001$	—	**20 ~ 12** $p < .001, r = 0.29$	20 ~ 19	20 ~ 16	20 ~ 19
Subtask Agreement $p = .002$	**75% ~ 67%** $p = .042, r = 0.20$	75% ~ 73%	75% ~ 76%	75% ~ 75%	75% ~ 80%
Label Agreement *n.s.*	—	73% ~ 75%	73% ~ 78%	73% ~ 76%	73% ~ 80%
Subtask Time $p < .001$	**8s ~ 26s** $p < .001, r = 0.70$	**8s ~ 16s** $p < .001, r = 0.51$	**8s ~ 13s** $p < .001, r = 0.39$	**8s ~ 11s** $p < .001, r = 0.28$	8s ~ 8s
Label Time $p = .05$	—	8s ~ 10s	8s ~ 9s	8s ~ 9s	8s ~ 7s
Total Time $p = .021$	193s ~ 179s	**193s ~ 343s** $p = .033, r = 0.19$	**193s ~ 285s** $p = .021, r = 0.21$	193s ~ 211s	193s ~ 205s
Abandonment $p = .014$	**8% ~ 22%** $p = .007, \phi = 0.03$	8% ~ 15%	*8% ~ 18%* $p = .072, \phi = 0.15$	*8% ~ 18%* $p = .082, \phi = 0.15$	8% ~ 12%
Understand $p = .036$	6% ~ 12%	6% ~ 7%	6% ~ 4%	6% ~ 2%	6% ~ 7%

Table 1. Summary of data and statistical comparisons. *p*-values given in the first column are for omnibus tests; in other columns, for post-hoc tests. Significant post-hoc comparisons highlighted in bold, borderline significant post-hoc comparisons highlighted in italics. Numerical variables (including *Subtask Agreement* and *Label Agreement*) are given as medians and Boolean variables as percentages.

- *Subtask Time*: The average time spent (in seconds) on each subtask for all subtasks completed, both label and map type.
- *Label Time*: The average time spent (in seconds) on each label type subtask. If workers are impacted by switching context between subtask types, they may become less efficient and take more time to complete label subtasks.
- *Total Time*: Total time spent on subtasks (in seconds). This variable was calculated as the time between seeing the first subtask and moving on to the survey.
- *Abandonment*: The percentage of workers who abandoned (accepted but did not complete) the HIT.

For time-related variables, any idle blocks of time 5 minutes or greater were removed from consideration. To identify significant differences, we used Pearson's chi-squared test for Boolean variables (*Abandonment* and survey responses) and Kruskal-Wallis test for numerical variables, as these were not normally distributed. If the omnibus test was significant, we then performed post-hoc pairwise comparisons between each condition and the `AllL` uniform condition, using Pearson's chi-squared test for Boolean variables and Wilcoxon rank-sum test for numerical variables. Pairwise tests were adjusted using the Bonferroni correction, scaling p-values by 5, when all possible comparisons were applicable, or by 4, for applicable comparisons. Unless otherwise noted, we report numerical averages as medians due to non-normality. To compute effect sizes, we used rank-biserial correlation (r) for numerical variables and phi (ϕ) for Boolean variables.

Given the potentially large number of post-hoc pairwise comparisons between conditions, we focused on two comparison groups:

- `AllL` against `AllM`. Comparing the two uniform conditions allows us to examine the impact of the different subtask types in isolation.
- `AllL` against each of the variety conditions containing both labels and maps; i.e., comparing a sequence of only label subtasks to inserting map subtasks into a label subtask sequence at different intervals.

Table 1 contains a summary of the variables and statistical comparisons. Figure 3 shows a survival chart, displaying worker retention over time for each of the conditions.

We found no significant differences in the survey responses other than for the response *"I did not understand the instructions"*, which we refer to as the variable *Understand*. Response rates for the other choices were: *"I was engaged in the task"* 36%, *"I thought my submission would not get approved"* 10%, *"I wanted to help the project"*

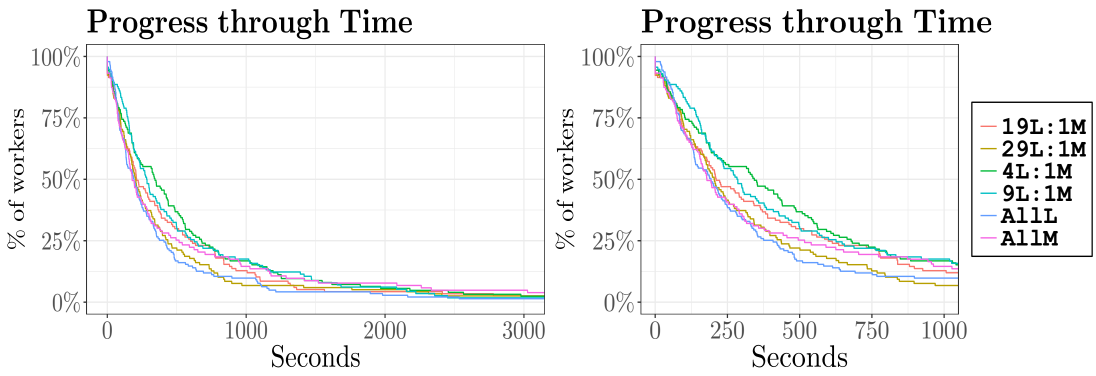

Figure 3. Survival chart for worker retention over time in the different conditions. The x-axis shows progress through time and the y-axis shows the percentage of workers retained up to that point; left shows up to 3000 seconds and right shows detail up to 1000 seconds. Note that early on, `4L:1M` and `9L:1M` retain more workers than conditions that serve map subtasks more or less frequently.

44%, *"I had no indication to stop"* 19%, *"I thought the payment was worth that much work"* 20%, *"I thought I would get paid more"* 8%, *"I wanted to see more images"* 28%, and *"Other"* 15%.

Findings

We summarize our findings in the following points:

The map subtask was generally more complex than the label subtask. Looking at the `AllL` against `AllM` comparison allows us to compare worker behavior on each of the subtask types themselves. The increased *Subtask Time* workers spent working on a single map subtask is consistent with the increased time expected with increased complexity (Campbell and Gingrich 1986). Additionally, among workers in the `AllM` condition, there was decreased *Subtask Agreement* and *Subtask Count*, along with increased in *Abandonment* of the HIT, compared to the `AllL` condition. Of note, though not statistically significant in all cases, is the observation that the `AllM` condition had the highest rate of abandonment and indication of reporting issues understanding the instructions. We do not consider this a surprising insight, rather supporting our initial assumption about the difference in complexity between subtask types.

Using only one type of subtask or the other did not impact total time spent on the task. Also looking at the `AllL` against `AllM` comparison, there was no significant difference in *Total Time* between the uniform subtask conditions, indicating that neither individual subtask type was inherently more engaging, with respect to time spent, than the other.

Interleaving subtask types did not observably impact speed or quality through distractions. When comparing `AllL` against each of the conditions with subtask variety, no significant pairwise comparisons were found among *Label Time* or *Label Agreement*. This indicates that workers remained focused on the task and the quality of their work was not negatively impacted by the introduction of subtask type switches.

In some conditions, inserting map subtasks into a label subtask sequence increased the time spent on the task. Again comparing `AllL` against the subtask variety conditions, workers in the `4L:1M` and `9L:1M` conditions spent significantly more *voluntary* time on the task, when compared to the `AllL` condition. However, the `4L:1M` condition was combined with a significant reduction in label count, while the `9L:1M` condition did not show a negative impact on label count. Also of note, though not statistically significant in all cases, is the observation that uniform subtask conditions (`AllL` and `AllM`) had the lowest *Total Time* among all conditions.

There was little, if any, observable impact on workers' subjective experience between conditions. There were no significant differences in the various survey responses among conditions. Even *Understand*, which was significant in the omnibus test, did not show significant differences in the post-hoc tests. This indicates that we did not observe a difference in workers' subjective experience and opinions regarding *self-reported* engagement, concern about getting approved, or the amount of work worth doing for the payment, and so forth. Despite this, we did observe differences in workers' actual behavior. However, it is of note that the top two selected survey responses indicated wanting to help the project, feeling engaged, and wanting to see more images, and the lowest were not understanding the instructions and desiring more pay, across all conditions. This provides some additional support to workers participating voluntarily even thought they were receiving payment.

We believe these observations indicate that the comparison between `AllL` and `9L:1M` is of particular interest. When compared with a sequence of simple subtasks (labels), interleaving a more complex subtask (maps) at a small interval increased the total time *voluntarily* spent on the HIT without observably negatively impacting other performance variables *of those workers who completed the HIT*. Figure 3 highlights the increased portion of workers in variety conditions with maps frequently interleaved who are retained early on. Examining other variety conditions indicates that the interval at which the map subtasks are interleaved matters. As the median *Subtask Count* was generally around 20 for conditions with many labels, it is possible that in the conditions with more space between the map subtasks, workers simply did not encounter enough maps to affect our measures, or most workers finished before even reaching a map.

DISCUSSION

In this study, we explored the effects of the variety of subtasks with differing complexity in crowdsourced disaster response, by inviting workers to complete a sequence of label and map subtasks—inspired by the MapMill disaster response project—served at various levels of frequency. We recruited paid workers through an MTurk HIT.

Our findings offer some interesting insights on how to design engaging tasks for disaster response. We believe that task design is important, not only for recruiting more volunteers, but also for improving retention and performance, in events that will otherwise face difficulty in attracting response participants. The increase in data volume can, in turn, facilitate more rapid deployment of response and recovery in areas struck by a disaster. This work constitutes a preliminary step into designing a platform for attracting participants to engage with disaster response efforts.

Although the results of our study provide initial support to the benefits of task variety in the design of crowdsourcing tasks, further study can help inform a deeper understanding of how different levels of variety and complexity affect worker performance and engagement.

Worker performance indicated a higher level of difficulty with the map subtask, which may have also contributed to lower rates of agreement and increased abandonment when map subtasks were frequent. Further work can explore lessening the rate of abandonment when workers are given such complex tasks.

This work examined only two specific types of subtasks; image labeling and locating images on map. Future work could be centered on expanding research to include other types of subtasks that are often found on crowdsourcing platforms like MTurk, such as manuscript transcription or sentiment analysis. It would also be interesting to explore variety among more than two types of subtask. We also only considered fixed intervals of providing the more complex map subtasks; in particular, variable or adaptive approaches to scheduling variety may be a fruitful area of exploration.

Finally, although we used voluntary time as a measure of behavioral engagement, we carried out our study in the context of paid crowdsourcing on MTurk, where participants were paid for participating. It remains to be confirmed that a similar effect would be present in purely voluntary crowdsourcing contexts.

ACKNOWLEDGMENTS

This work was supported by a Northeastern University TIER 1 grant, Google, and the New World Foundation in collaboration with Public Lab. We would like to thank the Civil Air Patrol and the U.S. Geological Survey for making the images available and the Mechanical Turk workers for their participation.

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Automatic Image Filtering on Social Networks Using Deep Learning and Perceptual Hashing During Crises

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ABSTRACT

The extensive use of social media platforms, especially during disasters, creates unique opportunities for humanitarian organizations to gain situational awareness and launch relief operations accordingly. In addition to the textual content, people post overwhelming amounts of imagery data on social networks within minutes of a disaster hit. Studies point to the importance of this online imagery content for emergency response. Despite recent advances in the computer vision field, automatic processing of the crisis-related social media imagery data remains a challenging task. It is because a majority of which consists of redundant and irrelevant content. In this paper, we present an image processing pipeline that comprises de-duplication and relevancy filtering mechanisms to collect and filter social media image content in real-time during a crisis event. Results obtained from extensive experiments on real-world crisis datasets demonstrate the significance of the proposed pipeline for optimal utilization of both human and machine computing resources.

Keywords

social media, image processing, supervised classification, disaster management

INTRODUCTION

The use of social media platforms such as Twitter and Facebook at the times of natural or man-made disasters has increased recently (Starbird et al. 2010; Hughes and Palen 2009). People post a variety of content such as textual messages, images, and videos online (Chen et al. 2013; Imran, Castillo, Diaz, et al. 2015). Studies show the significance and usefulness of this online information for humanitarian organizations struggling with disaster response and management (Peters and Joao 2015; Imran, Elbassuoni, et al. 2013; Daly and Thom 2016). A majority of these studies have however been relying almost exclusively on textual content (i.e., posts, messages, tweets, etc.) for crisis response and management. Contrary (or complementary) to the existing literature on using textual social media content for crisis management, this work focuses on leveraging the visual social media content (i.e., images) to show humanitarian organizations its utility for disaster response and management. While many are valuable, however, the sheer amount of images (most of which are irrelevant or redundant) is difficult to manage and digest for humanitarian organizations, let alone useful for emergency management. If processed timely and effectively, this information can enable early decision-making and other humanitarian tasks such as gaining situational awareness, e.g., through summarization (Rudra et al. 2016) during an on-going event or assessing the severity of the damage during a disaster (Ofli et al. 2016).

Analyzing the large volume of online social media images generated after a major disaster remains to be a challenging task in contrast to the ease of acquiring them from various social media platforms. A most popular solution is to use a hybrid crowdsourcing and machine learning approach to rapidly process large volumes of imagery data for disaster response in a time-sensitive manner. In this case, human workers (paid or volunteers (Reuter et al. 2015)) are employed to label features of interest (e.g., damaged shelters or blocked roads) in a set of images. These human-annotated images are then used to train supervised machine learning models to recognize such features in new unseen images automatically.

However, a large proportion of social media image data consists of irrelevant (see Figure 3) or redundant (see Figure 4) content. Many people just re-tweet an existing tweet or post irrelevant images, advertisement, even porn using event-specific hashtags. On the other hand, the time and motivation of human annotators are neither infinite nor free. Every crowdsourcing deployment imposes a cost in humanitarian organizations' volunteer base and budget. Annotators may burn down (reducing their effectiveness due to lack of motivation, tiredness, or stress) or drop out completely (reducing the humanitarian organizations' volunteer base). Since human annotations have a direct effect on the performance of the machine learning algorithms, deficiencies in the annotations can easily translate to shortcomings in the developed automatic classification systems. Therefore, it is of utmost importance to have many volunteers to provide annotations (i.e., *quantity*) and mechanisms to keep the annotation *quality* high.

One way to achieve this is to decrease the workload on the human annotators. For this purpose we develop an image processing pipeline based on deep learning that can automatically (i) detect and filter out images that are not relevant or do not convey significant information for crisis response and management, and (ii) eliminate duplicate or near-duplicate images that do not provide additional information neither to a classification algorithm nor to humanitarian organizations. Such a filtering pipeline will thus help annotators to focus their time and effort on making sense of useful image content only, which in turn helps improve the performance of the machine learning models. Among several potential use cases of the proposed image filtering pipeline on social networks, in this particular study, we focus on the use case of automatic damage assessment from images.

The main contributions of this study can be summarized as follows: (i) We propose mechanisms to purify the noisy social media image data by removing duplicate, near-duplicate, and irrelevant image content. (ii) We use the proposed mechanisms to demonstrate that a big chunk of the real-world crisis datasets obtained from online social networks consists of redundant or irrelevant content. (iii) Our extensive experimental evaluations underline the importance of the proposed image filtering mechanisms for optimal utilization of both human and machine resources. Specifically, our experimental results show that purification of social media image content enables efficient use of the limited human annotation budget during a crisis event, and improves both robustness and quality of the machine learning models' outputs used by the humanitarian organizations. (iv) We show that the state-of-the-art computer vision deep learning models can be adapted successfully to image relevancy and damage category classification problems on real-world crisis datasets. (v) Finally, we develop a real-time system with an image processing pipeline in place for analyzing social media data at the onset of any emergency event, which can be accessed at `http://aidr.qcri.org/`.

RELATED WORK

Despite the wealth of text-based analyses of social media data for crisis response and management, there are only a few studies analyzing the social media image content shared during crisis events. The importance of social media images for disaster management has been recently highlighted in (Peters and Joao 2015). The authors analyzed tweets and messages from Flicker and Instagram for the flood event in Saxony in 2013, and found that the existence of images within on-topic messages are more relevant to the disaster event, and the image content can also provide important information related to the event. In another study, Daly and Thom focused on classifying images extracted from social media data, i.e, Flickr, and analyzed whether a fire event occurred at a particular time and place (Daly and Thom 2016). Their study also analyzed spatio-temporal meta-data associated with the images, and suggested that geotags prove useful to locate the fire affected area.

Taking a step further, Chen et al. studied the association between tweets and images, and their use in classifying visually-relevant and irrelevant tweets (Chen et al. 2013). They designed classifiers by combining features from text, images and socially relevant contextual features (e.g., posting time, follower ratio, the number of comments, re-tweets), and reported an F1-score of 70.5% in a binary classification task, which is 5.7% higher than the text-only classification.

There are similar studies in other research domains (e.g., remote sensing), not necessarily using social media data though, that try to assess level of damage from aerial (Turker and San 2004; Fernandez Galarreta et al. 2015) and satellite (Pesaresi et al. 2007; Feng et al. 2014) images collected from disaster-hit regions.

Almost all of the aforementioned studies rely on the classical bag-of-visual-words-type features extracted from images to build the desired classifiers. However, since the introduction of Convolutional Neural Networks (CNN) for image classification in (Krizhevsky et al. 2012), state-of-the-art performances for many tasks today in computer vision domain are achieved by methods that employ different CNN architectures on large labeled image collections such as PASCAL VOC (Everingham et al. 2010) or ImageNet (Russakovsky et al. 2015). Recently, in the 2016 ImageNet Large Scale Visual Recognition Challenge (ILSVRC)[1], the best performance on image classification task is reported as 2.99% top-5 classification error by an ensemble method based on existing CNN architectures such as Inception Networks (Szegedy et al. 2015), Residual Networks (He et al. 2016) and Wide Residual Networks (Zagoruyko and Komodakis 2016).

More importantly, many follow-up studies have shown that the features learned automatically by these deep neural networks are transferable to different target domains (Donahue et al. 2014; Sermanet et al. 2013; Zeiler and Fergus 2014; Girshick et al. 2014; Oquab et al. 2014). This proves extremely useful for training a large network without overfitting when the target dataset is significantly smaller than the base dataset, as in our case, and yet achieving state-of-the-art performance in the target domain. Therefore, we consider this transfer learning approach in our study.

DATA COLLECTION AND ANNOTATION

We used publicly available AIDR platform (Imran, Castillo, Lucas, et al. 2014) to collect images from social media networks such as Twitter during four major natural disasters, namely, Typhoon Ruby, Nepal Earthquake, Ecuador Earthquake, and Hurricane Matthew. The data collection was based on event-specific hashtags and keywords. Table 1 lists the total number of images initially collected for each dataset. Figure 1 shows example images from these datasets.

Table 1. Dataset details for all four disaster events with their year and number of images.

Disaster Name	Year	Number of Images
Typhoon Ruby	2014	7,000
Nepal Earthquake	2015	57,000
Ecuador Earthquake	2016	65,000
Hurricane Matthew	2016	61,000

Human Annotations

We acquire human labels with the purpose of training and evaluating machine learning models for image filtering and classification. Although, there are several other uses of images from Twitter, in this work, we focus on damage severity assessment from images. Damage assessment is one of the critical situational awareness tasks for many humanitarian organizations. For this purpose, we obtain labels in two different settings. The first set of labels were gathered from AIDR. In this case, volunteers[2], are employed to label images during a crisis situation. In the second setting, we use the Crowdflower[3], which is a paid crowdsourcing platform, to annotate images. We provided the following set of instructions with example images for each category to the annotators for the image labeling task. To maintain high-quality, we required an agreement of at least three different annotators to finalize a task.

Damage Severity Levels Instructions

The purpose of this task is to assess the severity of damage shown in an image. The severity of damage in an image is the extent of physical destruction shown in it. We are only interested in physical damages like broken bridges, collapsed or shattered buildings, destroyed or cracked roads, etc. An example of a non-physical damage is the signs of smoke due to fire on a building or bridge—in this particular task, we do not consider such damage types. So in such cases, please select the "no damage" category.

[1] http://image-net.org/challenges/LSVRC/2016/results#loc
[2] Stand-By-Task-Force
[3] http://crowdflower.com/

Figure 1. Sample images with different damage levels from different disaster datasets.

1- Severe damage*: Images that show the substantial destruction of an infrastructure belong to the severe damage category. A non-livable or non-usable building, a non-crossable bridge, or a non-driveable road are all examples of severely damaged infrastructures.*

2- Mild damage*: Damage is generally exceeding minor [damage] with up to 50% of a building, for example, in the focus of the image sustaining a partial loss of amenity/roof. Maybe only part of the building has to be closed down, but other parts can still be used. In the case of a bridge, if the bridge can still be used, however, part of it is unusable and/or needs some amount of repairs. Moreover, in the case of a road image, if the road is still usable, however, part of it has to be blocked off because of damage. This damage should be substantially more than what we see due to regular wear or tear.*

3- Little-to-no damage*: Images that show damage-free infrastructure (except for wear and tear due to age or disrepair) belong to this category.*

Table 2 shows human annotation results in terms of labeled images for each dataset. Since the annotation was done on raw image collection without any type of prior filtering to clean the dataset, the resulting labeled dataset contains duplicate and irrelevant images.

REAL-TIME FILTERING OF IMAGES

To be effective during disasters, humanitarian organizations require real-time insights from the data posted on social networks at the onset of any emergency event. To fulfill such time-critical information needs, the data should be processed as soon as it arrives. That means the system should ingest data from online platforms as it is being posted, perform processing and analysis to gain insights in near real-time. To achieve these capabilities, in this paper, we present an automatic image filtering pipeline. Figure 2 shows the pipeline and its various important components.

Table 2. Number of labeled images for each dataset and each damage category.

Category	Nepal Earthquake	Ecuador Earthquake	Typhoon Ruby	Hurricane Matthew	Total
Severe	8,927	955	88	110	10,080
Mild	2,257	89	338	94	2,778
None	14,239	946	6,387	132	21,704
Total	25,423	1,990	6,813	336	34,562

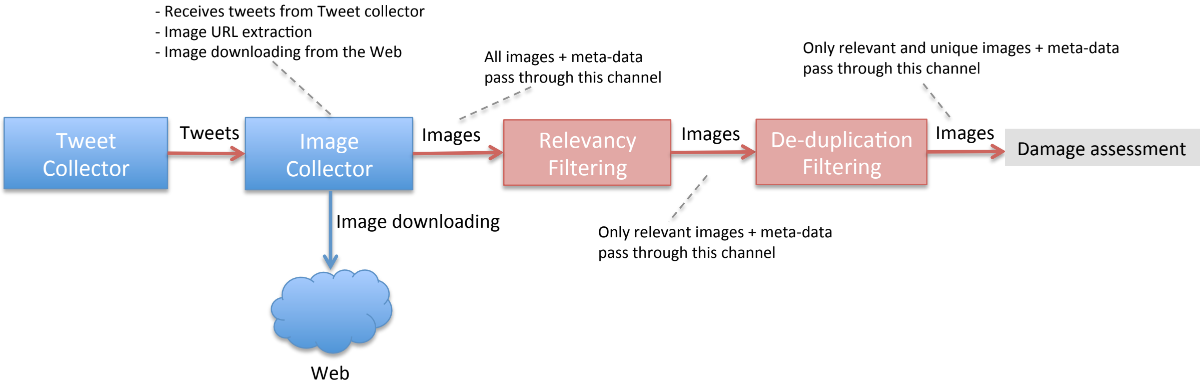

Figure 2. Automatic image filtering pipeline.

The first component in the pipeline is *Tweet Collector*, which is responsible for collecting tweets from Twitter streaming API during a disaster event. A user can collect tweets using keywords, hashtags, or geographical bounding boxes. Although, the pipeline can be extended to consume images from other social media platforms such as Facebook, Instagram, etc., in this paper we only focus on collecting images that are shared via the Twitter platform. The *Image Collector* component receives images from the Tweet collector and extracts image URLs from tweets. Next, given the extracted URLs, the Image Collector downloads images from the Web (i.e., in many cases from Flicker or Instagram). Then, there are the two most important components of the pipeline, i.e., the *Relevancy Filtering* and *De-duplication Filtering*, which we describe next in detail in respective subsections.

Relevancy Filtering

The concept of *relevancy* depends strongly on the definition and requirements of the task at hand. For example, if the goal is to identify all the news agencies reporting a disaster event, then images that display logos or banners constitute the most relevant portion of the data. On the other hand, if the goal is to identify the level of infrastructure damage after a disaster event, then images that contain buildings, roads, bridges, etc., become the most relevant and informative data samples. Since we have chosen damage assessment as our usecase, and collected human annotations for our datasets accordingly, our perception of relevancy in the scope of this study is strongly aligned with the latter example. Figure 3 illustrates example images that are potentially not relevant for damage assessment task.

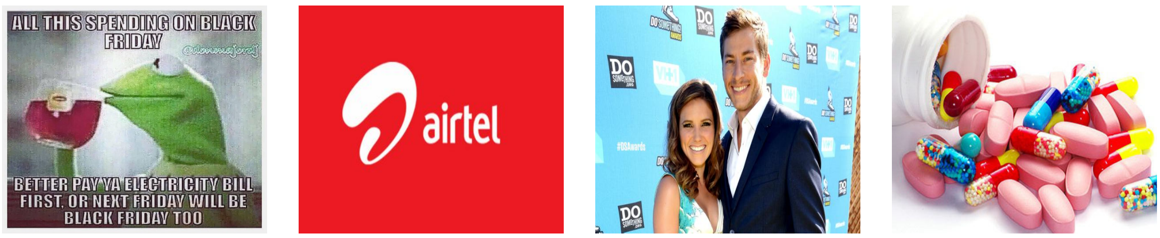

Figure 3. Examples of irrelevant images in our datasets showing cartoons, banners, advertisements, celebrities, etc.

It is important to note however that the human annotation process presented in the previous section is designed mainly for assessing the level of damage observed in an image, but no question is asked regarding the relevancy of the actual image content. Hence, we lack ground truth human annotations for assessing specifically the relevancy of an image content. We could construct a set of rules or hand-design a set of features to decide whether an image is relevant or not, but we have also avoided such an approach in order not to create a biased or restricted definition of relevancy that may lead to discarding potentially relevant and useful data. Instead, we have decided to rely on the human-labeled data to learn a set of image features that represent the subset of irrelevant images in our datasets, following a number of steps explained in the sequel.

Understanding the Content of Irrelevant Images

We assume the set of images labeled by humans as severe or mild belong to the relevant category. The set of images labeled as none, however, may contain two types of images (i) that are still related to disaster event but do not simply show any damage content, and (ii) that are not related to the disaster event at all, or the relation cannot be immediately understood just from the image content. So, we first try to understand the kind of content shared by the latter set of images, i.e., images that were originally labeled as none. For this purpose, we take advantage of the recent advances in computer vision domain, thanks to the outstanding performance of the convolutional neural networks (CNN), particularly in the object classification task. In this study, we use VGG-16 (Simonyan and Zisserman 2014) as our reference model, which is one of the state-of-the-art deep learning object classification models that performed the best in identifying 1000 object categories in ILSVRC 2014[4]. To understand which ImageNet object categories appear the most, we first run all of our images labeled by humans as none through the VGG-16 network to classify each image with an object category. We then look at the distribution of the most frequently occurring object categories, and include in our irrelevant set those images that are tagged as one of the following most-frequently-occurring 12 categories: *website, suit, lab coat, envelope, dust jacket, candle, menu, vestment, monitor, street sign, puzzle, television, cash machine, screen*. Finally, this approach yields a set of 3,518 irrelevant images. We also sample a similar number of images randomly from our relevant image set (i.e., images that are originally labeled as severe or mild) to create a balanced dataset of 7,036 images for training the desired relevancy filter as a binary classifier.

Building a Binary Classifier by Fine-tuning a Pre-trained CNN

The features learned by CNNs are proven to be transferable and effective when used in other visual recognition tasks (Yosinski et al. 2014; Ozbulak et al. 2016), particularly when training data are limited and learning a successful CNN from scratch is not feasible due to overfitting. Considering that we also have limited training data, we adopt a transfer learning approach, where we use the existing weights of the pre-trained VGG-16 network (i.e., millions of parameters, trained on millions of images from the ImageNet dataset) as an initialization for fine-tuning the same network on our own training dataset. We also adapt the last layer of the network to handle binary classification task (i.e., two categories in the softmax layer) instead of the original 1,000-class classification. Hence, this transfer learning approach allows us to transfer the features and the parameters of the network from the broad domain (i.e., large-scale image classification) to the specific one (i.e., relevant-image classification). The details of the training process and the performance of the trained model is reported in the Experimental Framework section.

De-duplication Filtering

A large proportion of the image data posted during disaster events contains duplicate or near-duplicate images. For example, there are cases when people simply re-tweet an existing tweet containing an image, or they post images with little modification (e.g., cropping/resizing, background padding, changing intensity, embedding text, etc.). Such posting behavior produces a high number of near-duplicate images in an online data collection. Figure 4 shows some examples of near-duplicate images.

In order to train a supervised machine learning classifier, as in our case, human-annotation has to be performed on a handful of images. In this case, ideally, train and test sets should be completely distinct from each other. However, the presence of duplicate images may violate this fundamental machine learning assumption, that is, the training and test sets become polluted as they may contain similar images. This phenomenon introduces a bias which leads to an artificial increase in the classification accuracy. Such a system, however, operates at a higher misclassification rate when predicting unseen items.

To detect exact as well as near-duplicate images, we use the Perceptual Hashing (pHash) technique (Lei et al. 2011; Zauner 2010). Unlike the cryptographic hash functions like MD5 (Rivest 1992) or SHA1, a perceptual hash represents the fingerprint of an image derived from various features from its content. An image can have different digital representation, for example, due to cropping, resizing, compression or histogram equalization. Traditional cryptographic hashing techniques are not suitable to capture such changes in the binary representation, which is a

[4]http://image-net.org/challenges/LSVRC/2014/results#clsloc

Figure 4. Examples of near-duplicate images found in our datasets.

common case in near duplicate images. Whereas perceptual hash functions maintain *perceptual equality* of images hence they are robust in detecting even slight changes in the binary representation of two similar images.

The de-duplication filtering component in our system implements the Perceptual Hashing technique[5] to determine whether or not a given pair of images are same or similar. Specifically, it extracts certain features from each image, and computes a hash value for each image based on these features, and compares the resulting pair of hashes to decide the level of similarity between the images. During an event, the system maintains a list of hashes computed for a set of distinct images it receives from the Image collector module. To determine whether a newly arrived image is a duplicate of an already existing image, hash value of the new image is computed and compared against the list of stored hashes to calculate its distance from the existing image hashes. In our case, we use the Hamming distance to compare two hashes. If an image with a distance value smaller than d is found in the list, the newly arrived image is considered as duplicate. The details regarding the optimal value of d are given in the Experimental Framework section. We always keep the recent 100k hashes in our physical memory for fast comparisons. This number obviously depends on the size of available memory in the system.

EXPERIMENTAL FRAMEWORK

For the performance evaluation of the different system components, we report on several well-known metrics such as accuracy, precision, recall, F1-score and AUC. Accuracy is computed as the proportion of correct predictions, both positive and negative. Precision is the fraction of the number of true positive predictions to the number of all positive predictions. Recall is the fraction of the number of true positive predictions to the actual number of positive instances. F1-score is the harmonic mean of precision and recall. AUC is computed as the area under the precision-recall curve.

Tuning the Individual Image Filtering Components

In this section, we elaborate on the tuning details of our individual relevancy and de-duplication filtering modules as well as their effects on raw data collection from online social networks.

Training and Testing the Performance of the Relevancy Filtering

We use 60% of our 7,036 images for training and 20% for validation during fine-tuning of the VGG-16 network. We then test the performance of the fine-tuned network on the remaining 20% of the dataset. Table 3 presents the performance of the resulting relevancy filter on the test set. Almost perfect performance of the binary classifier stems from the fact that relevant and irrelevant images in our training dataset have completely different image characteristics and content (as can be seen from the example images in Figures 1 and 3). This meets our original relevancy filtering objective to remove only those images that are surely irrelevant to the task at hand. Note that we reserve these 7,036 images only for relevancy filter modeling, and perform the rest of the experiments presented later using the remaining 27,526 images.

[5]http://www.phash.org/

Table 3. Performance of the relevancy filter on the test set.

AUC	Precision	Recall	F1
0.98	0.99	0.97	0.98

Learning an Optimal Distance Threshold for the De-duplication Filtering

To detect duplicate images, we first learned an optimal distance d as our threshold to decide whether two images are similar or distinct, (i.e., two images with distance $\leq d$ are considered duplicate). For this purpose, we randomly selected 1,100 images from our datasets and computed their pHash values. Next, Hamming distance for each pair is computed. To determine the optimal distance threshold, we manually investigated all pairs with a distance between 0 to 20. Pairs with distance > 20 look very distinct, thus not selected for manual annotation. We examined each pair and assigned a value of 1, if the images in a pair are the same and 0 otherwise. Figure 5 shows the accuracy computed based on the human-annotations, i.e., the number of correct predictions (including duplicate and not-duplicate) by machine at a given threshold value. We can clearly observe high accuracy with distance values $d \leq 10$, however, after that the accuracy decreases drastically. Based on this experiment, a distance threshold $d = 10$ is selected.

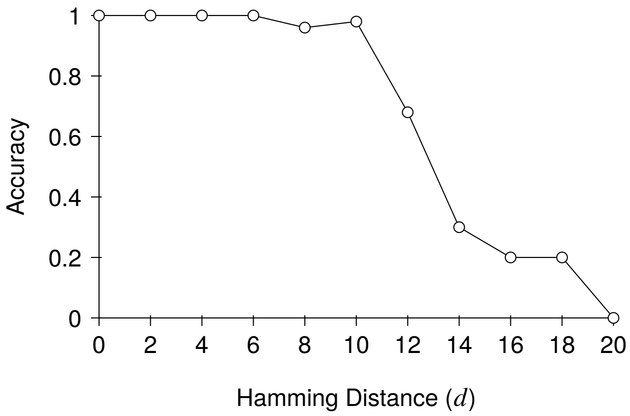

Figure 5. Estimation of distance threshold d for duplicate image detection.

Effects of the Individual Image Filtering Components on Raw Data Collection

To illustrate the benefit of image filtering components as well as to understand the useful proportion of the incoming raw image data from online social networks, we apply our proposed relevancy and de-duplication filtering modules on the remaining 27,526 images in our dataset. Table 4 presents the number of images retained in the dataset after each image filtering operation. As expected, relevancy filtering eliminates 8,886 of 18,186 images in none category, corresponding to an almost 50% reduction. There are some images removed from the severe and mild categories (i.e., 212 and 164, respectively) but these numbers are in the acceptable range of 2% error margin for the trained relevancy classifier as reported earlier. De-duplication filter, on the other hand, removes a considerable proportion of images from all categories, i.e., 58%, 50% and 30% from severe, mild and none categories, respectively. The relatively higher removal rate for the severe and mild categories can be explained by the fact that social media users tend to re-post the most relevant content more often. Consequently, our image filtering pipeline reduces the size of the raw image data collection by almost a factor of 3 (i.e., an overall reduction of 62%) while retaining the most relevant and informative image content for further analyses which we present in the next section.

Table 4. Number of images that remain in our dataset after each image filtering operation.

Category	Raw Collection	After Relevancy Filtering	After De-duplication Filtering	Overall Reduction
Severe	7,501	7,289	3,084	59%
Mild	1,839	1,675	844	54%
None	18,186	9,300	6,553	64%
All	27,526	18,264	10,481	**62%**

Evaluating the Effects of Image Filtering Components on Damage Assessment Performance

In this section, we analyze the effects of irrelevant and duplicate images on human-computation and machine training. We choose the task of damage assessment from images as our usecase, and consider the following four settings:

- S1: We perform experiments on raw collection by keeping duplicate and irrelevant images intact. The results obtained from this setting are considered as a baseline for the next settings.
- S2: We only remove duplicate images and keep the rest of the data the same as in S1. The aim of this setting is to learn the difference with and without duplicates.
- S3: We only remove irrelevant images and keep the rest of the data the same as in S1. The aim here is to investigate the effects of removing irrelevant images from the training set.
- S4: We remove both duplicate and irrelevant images. This is the ideal setting, which is also implemented in our proposed pipeline. This setting is expected to outperform others both in terms of budget utilization and machine performance.

For training a damage assessment classifier, we again take the approach of fine-tuning a pre-trained VGG-16 network. This is the same approach that we use for relevancy filter modeling before, but this time (i) the network is trained for 3-class classification where classes are severe, mild, and none, and (ii) the performance of the resulting damage assessment classifier is evaluated in a 5-fold cross-validation setting rather than using a train/validation/test data split.

Effects of Duplicate Images on Human Annotations and Machine Training

To mimic the real-time annotation and machine learning setting during a crisis event, we assume that a fixed budget of 6,000 USD is available for annotation. For simplicity, we assume 1 USD is the cost to get one image labeled by human workers. Given this budget, we aim to train two classifiers; one with duplicates (S1) and another without duplicates (S2).

In S1, the system spends full 6,000 USD budget to get 6,000 labeled images from the raw collection, many of which are potential duplicates. To simulate this, we randomly select 6,000 images from our labeled dataset while maintaining the original class distributions as shown in the S1 column of Table 5. We then use these 6,000 images to train a damage assessment classifier as described above, and present the performance of the classifier in the S1 column of Table 6.

In S2, we take the same subset of 6,000 images used in S1, and run them through our de-duplication filter to eliminate potential duplicates, and then, train a damage assessment classifier on the cleaned subset of images. S2 column of Table 5 shows the class-wise distribution of the remaining images after de-duplication. We see that 598, 121, and 459 images are marked as duplicate and discarded in severe, mild, and none categories, respectively. Evidently, this indicates a budget waste of 1,178 USD (~20%) in S1, which could have been saved if the de-duplication technique was employed. The performance of the damage assessment classifier trained on the cleaned data is shown in S2 column of Table 6. Although we observe an overall decrease in all performance scores as compared to S1, we claim that the performance results for S2 are more trustworthy for the following reason: In S1, due to the appearance of duplicate or near-duplicate images both in training and test sets, the classifier gets biased and thus shows artificially high but unreliable performance.

Table 5. Number of images used in each setting: S1 (with duplicates + with irrelevant), S2 (without duplicates + with irrelevant), S3 (with duplicates + without irrelevant), S4 (without duplicates + without irrelevant).

Category	S1	S2	S3	S4
Severe	1,636	1,038	2,395	1,765
Mild	400	279	550	483
None	3,964	3,505	3,055	3,751
All	6,000	4,822	6,000	6,000

Table 6. Precision, Recall, F1 and AUC scores: S1 (with duplicates + with irrelevant), S2 (without duplicates + with irrelevant), S3 (with duplicates + without irrelevant), S4 (without duplicates + without irrelevant).

	S1				S2				S3				S4			
	AUC	Pre.	Rec.	F1	AUC	Pre.	Rec.	F1	AUC	Pre.	Rec.	F1	AUC	Pre.	Rec.	F1
None	0.98	0.91	0.96	0.94	0.98	0.91	0.97	0.94	0.94	0.86	0.93	0.90	0.95	0.86	0.95	0.91
Mild	0.31	0.48	0.18	0.25	0.26	0.41	0.12	0.18	0.37	0.53	0.20	0.29	0.30	0.55	0.14	0.23
Severe	0.95	0.88	0.89	0.88	0.91	0.85	0.84	0.84	0.95	0.88	0.91	0.90	0.91	0.86	0.85	0.86
Avg.	0.75	0.74	0.68	0.69	0.72	0.72	0.64	0.65	0.75	0.76	0.68	0.70	0.72	0.76	0.65	0.67

Effects of Irrelevant Images on the Damage Assessment Performance

In terms of machine training, the level of noise in a dataset determines the quality of the trained model, and hence, the overall performance of the designed system (i.e., high level of noise leads to a low-quality model, which in turn, leads to a poor system performance). In terms of human annotation, a noisy dataset also causes sub-optimal use of the available budget. Even though removing irrelevant images from our datasets helps us in both directions, in this section we focus only on the machine training aspect of the problem as we have already exemplified the effect of such an operation on human annotation in the previous section.

Recall that in S1 we sample 6,000 images directly from the raw collection of 27,526 images. In S3 we first apply relevancy filtering operation on the raw collection and then sample 6,000 images from the clean set of 18,264 images. Note that this 6,000 sample may still contain duplicate or near-duplicate images. Even though the training data for S1 and S3 are not exactly the same, we can still try to compare the performance of the damage assessment model with and without irrelevant images. As we see from S1 and S3 columns of Table 6, the scores for none category in S3 are lower than those in S1 whereas the scores for severe and mild categories in S3 are higher than those in S1. After macro-averaging the scores for all categories, we see that overall F1-score for S3 is 1% higher than the overall F1-score for S2. Though macro-averaged AUC scores seem to be the same. However, we already know from the previous section that having duplicate or near-duplicate images in the training set yield untrustworthy model results. Hence, we do not intend to elaborate any further on this comparison.

In the ideal setting (S4), we discard both duplicate and irrelevant images from the raw data collection, and then sample 6,000 images from the remaining clean set of 10,481 images. S4 column of Table 6 presents the results of the damage assessment experiment on the sampled dataset, which does not contain duplicate and irrelevant images. If we compare the performance results for S3 and S4, we see that removing duplicate images from the training data eliminates the artificial increase in the performance scores, which is in agreement with the trend observed between S1 and S2.

More interestingly, we can see the benefit of removing irrelevant images when the data is already free from duplicates. That is, we can compare the results of S2 and S4, even though the training data for both settings are not exactly the same. At the category level, we observe a similar behavior as before, where the scores for none category in S4 are slightly lower than those in S2 while the scores for severe and mild categories in S4 are slightly higher than those in S2. If we compare the macro-averaged F1-scores, we see that S4 outperforms S2 by a small margin of 2%. In order to assess whether this difference in F1-scores between S2 and S4 is significant or not, we perform a permutation test (or sometimes called a randomization test) in the following manner. We randomly shuffle 1,000 times the input test image labels and the output model predictions within a common pool of S2 and S4 image subsets. Then for each shuffle, we compute the difference in F1-scores for S2 and S4. Eventually, we compare the observed F1-score distance against the distribution of such sampled 1,000 F1-score differences to see if the observed value is statistically significantly away from the mean of the sample distribution. In our case, we get $p = 0.077$, which is not statistically significant but shows a certain trend toward significance.

Figure 6 shows the precision-recall curves for all four settings. First of all, it is evident that in the three-class classification task, the hardest class (according to the classifier performance) is the mild damage category. In all settings, we observe a low AUC for mild category compared to the other two categories. One obvious justification of this is the low prevalence of the mild category compared to other categories (see Table 5). More training data should fix this issue, which we plan as future work. Otherwise, in all settings, the classifiers achieve high accuracy in classifying images into severe and none categories.

DISCUSSION

User-generated content on social media at the time of disasters is useful for crisis response and management. However, understanding this high-volume, high-velocity data is a challenging task for humanitarian organizations.

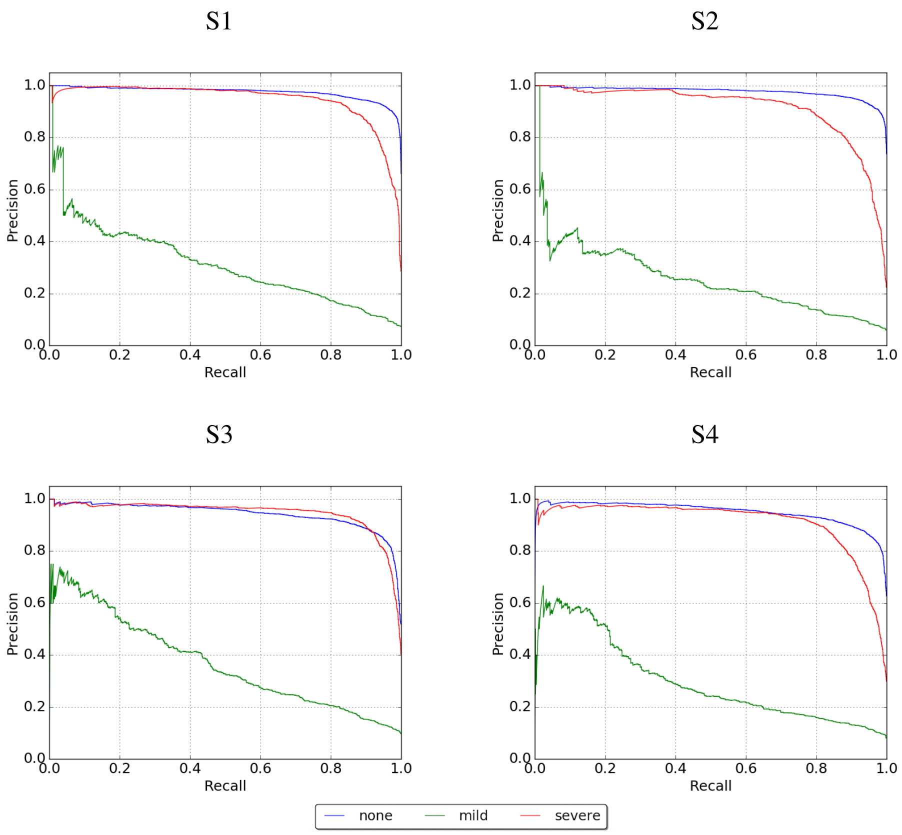

Figure 6. Precision-recall curves for all four settings: S1 (with duplicates + with irrelevant), S2 (without duplicates + with irrelevant), S3 (with duplicates + without irrelevant), S4 (without duplicates + without irrelevant).

In this paper, we presented a social media image filtering pipeline to specifically perform two types of filtering: i) image relevancy filtering and ii) image de-duplication.

This work is a first step towards building more innovative solutions for humanitarian organizations to gain situational awareness and to extract actionable insights in real time. However, a lot has to be done to achieve that goal. For instance, we aim to perform an exploratory study to determine whether there are differences between the key image features for specific event types, e.g., how key features for earthquake images differ from key features for hurricane images. This type of analysis will help us to build more robust classifiers, i.e., either general classifiers for multiple disaster types or classifiers specific to certain disaster types.

Moreover, as in the current work, we use labeled data from two different sources (i.e., paid and volunteers). It is worth performing a quality assessment study of these two types of crowdsourcing, especially in the image annotation context, to understand if there are differences in the quality of label annotation agreements between annotators from two diverse platforms, i.e., Crowdflower *vs.* AIDR. We consider this type of a quality assessment study as a potential future work.

Understanding and modeling the *relevancy* of certain image content is another core challenge that needs to be addressed more rigorously. Since different humanitarian organizations have different information needs, the definition of relevancy needs to be adapted or formulated according to the particular needs of each organization. Adapting a baseline relevancy model or building a new from scratch is a decision that has to be made at the onset of a crisis event, which is what we aim to address in our future work.

Besides relevancy, the veracity of the extracted information is also critical for humanitarian organizations to gain situational awareness and launch relief efforts accordingly. We have not considered evaluating the veracity of images for a specific event in this paper. However, we plan to tackle this important challenge in the future.

CONCLUSION

Existing studies indicate the usefulness of imagery data posted on social networks at the time of disasters. However, due to large amounts of redundant and irrelevant images, efficient utilization of the imagery content both using crowdsourcing or machine learning is a great challenge. In this paper, we have proposed an image filtering pipeline, which comprised of filters for detecting irrelevant as well as redundant (i.e., duplicate and near-duplicate) images in the incoming social media data stream. To filter out irrelevant image content, we used a transfer learning approach based on the state-of-the-art deep neural networks. For image de-duplication, we employed perceptual hashing techniques. We also performed extensive experimentation on a number of real-world disaster datasets to show the utility of our proposed image processing pipeline. We hope our real-time online image processing pipeline facilitates consumption of social media imagery content in a timely and effectively manner so that the extracted information can further enable early decision-making and other humanitarian tasks such as gaining situational awareness during an on-going event or assessing the severity of damage during a disaster.

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A #cultural_change is needed. Social media use in emergency communication by Italian local level institutions

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ABSTRACT

We discuss the results of a research project aimed at exploring the use of social media in emergency communication by officers operating at a local level. We performed 16 semi-structured interviews with national level expert informants, and with officers operating at the municipality and province (prefectures) level in an Italian region (respondents were selected based on their involvement in emergency communication and/or emergency management processes). Social media usage appears distributed over a *continuum of engagement*, ranging from very basic usage to using social media by adopting a *broadcasting* approach, to deeper engagement, which also includes continuous interaction with citizens. Two main attitudes emerge both in the narrative style and in social media representations: some respondents seem to adopt an *institutional* attitude, while others adopt a *practical-professional* attitude. Among the main barriers to a broader adoption of social media, *cultural* considerations seem to prevail, along with the lack of personnel, a general concern toward social media communication reliability, and the perceived distance between the formal role of institutions and the informal nature of social media communication.

Keywords

Social media, local level, emergency communication, barriers

INTRODUCTION AND BACKGROUND

Social media have proven to be effective communication tools both during and in the aftermath of natural disasters, offering timely information both to emergency managers and affected populations, providing situational awareness and supporting emergency recovery processes. In order to better understand social media emergency communication processes, scholars have analyzed several case studies, focusing on different contexts and social media platforms, and considering both *top-down* and *bottom-up* processes. From a *top-down* perspective, scholars have analyzed institutional communication and emergency management processes (Hughes, St. Denis, Palen and Anderson, 2014; Giacobe and Soule, 2014), and have considered the role of media organizations (Mularidharan et al., 2011). From a *bottom-up* perspective, scholars have studied the ways in which affected populations engage in social media-enabled self-organizing communication processes in the aftermath of disasters (Starbird & Palen, 2011; White, Palen & Anderson, 2014). Research has also focused on the interactions between organizations and different kinds of publics producing and consuming information during crises (Hughes and Tapia, 2015), underlining that “[s]ystematic knowledge is needed on the relative importance of different kinds of sources” (Sommerfeldt, 2016, p. 19), when relying on social media as a part of the relief effort process. In such a context, scholars have underlined the need to overcome “the ‘us against them’ mentality that exists between some emergency managers and journalists” (Liu, Fraustino & Jin, 2015, p. 60) or other social media creators.

Institutions need to find their way to become influential on social media in order to be able to spread their message to a large and relevant audience. Hughes et al. (2014), for instance, analyze social media usage in formal emergency management, underlining several challenges for broader social media adoption, which include changes in its role and responsibility, concerns with liability, deluge of data, trustworthiness of citizen-generated data, reliability of social media networks, and information overload. On the other hand, *bottom-up* communication could provide institutions with meaningful information from the affected populations, following the *Voluntweeters* model proposed by Starbird and Palen (2011), to the idea of recruiting "social media savvy" users, and involve them in emergency response processes on a local basis (Cooper et al., 2015), or to consider the role of *humans as sensors* (Earle et al., 2010; Cooper et al., 2015).

Social media adoption by institutions, both to spread and to gather information, appears uneven in different national contexts, and even when comparing different regions within a single country. After several natural disaster situations that hit Italy in recent years, for instance, citizens complained about the lack, or inadequacy, of institutional communication on social media, showing, at the same time, great interest in finding reliable and verified information (Comunello et al., 2016). Different case studies have highlighted that during heavy floods or earthquakes, Italian institutions were not generally among the most influential Twitter accounts, as this is a function more likely exerted by citizens, (Twit)stars, or media outlet accounts (Comunello, 2014; Comunello et al., 2016). On the other hand, relevant differences are to be found, in the Italian context, at a local and regional level. When considering the use of standardized hashtags for weather warnings on Twitter, for instance, citizens were the main drivers of its adoption and "curation" (leading to its usage to mainly spread verified information, focusing on situational awareness) during the November 2013 Sardinia floods (Parisi, Comunello, Amico, 2014); in the case of the January 2014 Toscana weather warnings, on the other hand, institutions supported the use of the predefined hashtag, achieving a similar goal, and reaching an influential role in Twitter conversations (Grasso and Crisci, 2016).

In more general terms, Internet and social media communication by Italian public institutions is still uneven. Research highlights a few best practices, along with several cases in which the potential of digital communication still remains unexploited. Data from the National Statistics Institution show, for instance, that only 29% of Italian Internet users access public institutions' websites (ISTAT, 2015), while the *fans of* 10 Facebook pages managed by Italian municipalities agree that these pages are "far from fulfilling their fans' expectations" (Lovari and Parisi, 2015, p. 209). Digital communication by Italian public institutions in general is described as far from a participatory practice (Faccioli, 2016), being oriented towards *broadcasting* rather than interactive models (Lovari and Parisi, 2015). Furthermore, no explicit reference to social media communication is to be found in job descriptions for public servants; those with the role of social media managers generally do so on a voluntary basis, receiving only informal support from their department.

In this paper, we focus on social media emergency communication by Italian public institutions at a local level. We decided to focus on the local level for several reasons. First, the Italian civil protection system is strongly grounded at the local (municipality) level. The mayor is the first civil protection authority, and he or she is in charge of deciding whether to request intervention from higher level institutions (up to the national level, when the Civil Protection Department is involved). Moreover, according to communication officers of the Civil Protection Department, this is also the reason why the department has never established any social media account, relying on the local level for social media communication with citizens. Second, when asked about the preferred sources for getting emergency information, Italian citizens prioritized the local level, also underlining the role of the mayor (Lombardi, 2005, pp. 94-99). Third, this research is inspired by the work by Hiltz, Kushma, Plotnick and Tapia (namely, Hiltz, Kushma and Plotnick, 2014; Plotnick, Hiltz, Kushma and Tapia, 2015), who focused on local level emergency managers in the US (at a county level). More specifically, the authors highlighted the main barriers for social media usage to spread and gather information: lack of staff (quantity), lack of formal social media policies, lack of staff (skills), and low reliance on the trustworthiness of user-generated content. As a result, the authors underline that local level agencies in the US "are not yet ready to embrace SM and use it to its fullest potential" (Plotnick et al., p. 10).

We decided to conduct a similar study in the Italian context, with the goal of exploring social media usage, social media perception, and the barriers to a broader social media adoption by public institution emergency managers at a local level, involving officers operating in municipalities and prefectures.

METHODS AND RESEARCH QUESTIONS

Considering the complexity of the Italian civil protection system, and the peculiarities of digital and social media communication by Italian public institutions, as well as following the example of the aforementioned scholars, we decided to perform an exploratory study, relying on qualitative research methods. More specifically, we first performed semi-structured interviews with four experts working as communication officers at the Department of Civil Protection, in order to get a comprehensive picture of the Italian civil protection system, and of the related communication processes.

Subsequently, we decided to focus on a single Italian region[1], which was chosen based on information provided by the expert informants, because it is at the national average with regard to social media emergency communication (neither *best practices* nor *laggards* were selected at this step). Additionally, the expert informants helped us select two social media managers working for Italian municipalities (outside the selected region) whose social media emergency communication practices are considered *best practices* at a national level.

With regard to the selected region, we decided to focus both on municipalities and provinces. While provinces are currently being eliminated from the Italian institutional system, prefectures (the institutions that represent the government at the province level) are responsible for emergency management at the province level (they are directly in charge of any emergency that is too big to be managed at the municipal level). More specifically, we decided to write a formal letter to every mayor of province capital municipality[2] in the selected region, and to every prefect of the same region, asking for a delegate for a face-to-face interview. Delegates could be involved at any level in emergency management and/or communication. Council members and vice-prefects in charge of civil protection as well as (digital) communication officers were designated[3]. Overall, we conducted 16 semi-structured interviews, which lasted between 30 and 60 minutes.

Our research questions were the following:

1. What social media platforms are used, and for what purposes, by local level emergency managers? What are the prevailing usage patterns?
2. How are these platforms perceived by managers and operators?
3. What are the main barriers to broader social media adoption for spreading or gathering emergency-related information?
4. What *desiderata* are expressed by managers and operators with regard to platform features or organizational issues?

The interview outline starts by addressing the civil protection system and the coordination between the different institutions involved. Such questions are aimed both at a better understanding of the system itself, and at understanding the particular ways in which each respondent understands it. We then focused on emergency communication, asking them to recall and describe a specific situation where they had been directly involved. At this step, we avoided directly mentioning social media, encouraging respondents to freely mention every relevant channel they relied on. We subsequently focused on the role of social media in gathering and sharing emergency-related information, considering motivations, usage practices, perceived advantages and disadvantages, and perceived barriers. Finally, we focused on the respondents' wishes with regard to platform features or to organizational aspects. We adopted a flexible interview style, asking for examples and further information when relevant.

Interviews were voice-recorded and transcribed, and underwent thematic analysis (Boyatzis, 1998; Braun and Clarcke, 2006). More specifically, interview transcriptions were analyzed in order to generate initial codes. The coding process was conducted jointly by the two researchers, who largely discussed excerpts whose coding appeared problematic or ambiguous. Codes were collated into potential themes; themes were reviewed and a thematic map was generated, which included themes and subthemes. According to Boyatzis, "a theme is a pattern found in the information that at the minimum describes and organizes possible observations or at the maximum interprets aspects of the phenomenon" (1998, p. vii). In our research, both kinds of themes emerged. More specifically, themes describing and organizing observations are: communication practices (subthemes: internal communication, external communication), social media perception (subthemes: positive perceptions, negative perceptions), barriers to social media usage (subthemes: material barriers, immaterial/cultural barriers). Two additional themes contribute to interpreting the phenomenon. On the one hand, some of the respondents'

[1] To protect respondents' privacy, we decided not to disclose which specific region we focused on. Moreover, we will not provide detailed information about respondents' job descriptions or sociodemographic data. Interview excerpts will be attributed by using the following labels: "Mun", to refer to respondents working at a municipality; "Pref", to refer to respondents working at a Prefecture; "CP", to refer to respondents working at the civil protection department. Respondents belonged to Prefectures (6), Municipalities (6), Civil Protection Department (4).

[2] Province capital municipalities in the selected region include very large cities and medium-small sized cities.

[3] One administration never answered our request, while two other administrations answered without providing any delegate to be interviewed. Three administrations involved more than one respondent. The remaining administrations involved one respondent. As we formally asked to the Mayor and the Prefect, we interviewed all the delegates, without performing any other selection among them, when more than one respondent was involved.

answers appear as mainly oriented toward an *institutional* attitude; in this case, references to the law and to the formal role of institutions are repeated throughout the interview, and their tone of voice seems more formal, including several juridical terms. On the other hand, other respondents had a more *practical-professional* attitude; in this case, the overall expressive style seemed less formal, and their language included several technical terms referring to digital communication and social media management, while their overall representation of emergency communication processes was less bound to formalized roles, and more to achieving practical goals[4].

RESULTS AND DISCUSSION

This section is organized as follows: we first focus on communication practices, considering internal and external communication, and information spreading and gathering. Afterwards, we focus on their perception of social media platforms. We then focus on the main barriers to broader social media adoption, as perceived by the respondents. Finally, we explore the wishes expressed by respondents, considering both social media platform features and organizational issues. When analyzing the perception of social media platforms and the barriers to broader social media adoption, the discussion is organized around the two aforementioned attitudes.

Communication practices and social media usage patterns

When considering communication practices, a multifaceted picture emerges: different institutions rely on different communication strategies as well as on different channels. As no shared guidelines are to be found, channel selection is generally an individual choice, often dependent both on operator skills and attitudes, and on contextual considerations. More specifically, almost all of the respondents reported using the institutional website, while a majority of them mentioned Facebook and Twitter. Other platforms, such as WhatsApp, Instagram, and certified email, were mentioned by less than half of the respondents.

Internal communication

When considering internal communication, many respondents mentioned face-to-face encounters, as well as *traditional* systems, such as faxes and SMS. When mentioning such systems, many of the respondents referred to them as “old fashioned” systems, showing some regret about their use; some of them, however, underlined the issues experienced when trying to introduce “newer” communication systems.

When it comes to coordination, respondents underlined the need to integrate formal—albeit *traditional*—communication systems (such as mailing lists and phone calls) with informal ones, which are perceived as more advanced (e.g. WhatsApp groups involving colleagues working for different departments). It is noteworthy that experimenting with tools and practices that are perceived as innovative is generally related to an informal, unofficial domain, while formal procedures are depicted as bureaucratic and not time-effective. On the other hand, respondents also underlined the legal responsibilities that are related to their actions, thus recalling the role of certified email as the only tool that is able to provide them with legal protection.

Communicating with citizens: information-spreading

Consistent with literature on digital communication by Italian public institutions (Faccioli, 2016), digital media are generally used following a *broadcasting* logic (sharing information with the public), while less attention is paid to gathering information from the public.

Several respondents explained that their institutions mainly rely on traditional channels to provide information to the general public. They mentioned brochures and leaflets, as well as the local press, describing such tools as the most effective means to reach their goals, given contextual considerations and citizen characteristics (several respondents, for instance, emphasized the older age of a significant proportion of the inhabitants in their territory).

When considering digital platforms as tools for information-sharing, the most commonly used is the institutional website, followed by Facebook. In this regard, some institutions manage a Facebook page, while others still rely on a personal profile (referring to the municipality or to the prefecture as if they were individuals); in some municipalities, moreover, a central role, even in emergency communication, is played by the mayor’s or the

[4] Out of 16 respondents, 8 appear as mainly oriented toward an *institutional* attitude; 7 appear as mainly oriented toward a *practical-professional* attitude; 1 shows traits of both attitudes.

council member's personal profile on Facebook, creating an overlap between political and institutional communication, as already described in the literature on Italian institutional communication (Faccioli, 2016).

Respondents operating in administrations that were designed as *best practices*, on the other hand, are able to overcome some of the issues mentioned by other administrations. For instance, despite the large proportion of an older population, one respondent recalls having reached (*organic reach*) around 50% of people living in his municipality during a recent emergency. In this case, the use of Facebook as an institutional communication channel, emphasizing its role in emergencies, was promoted through traditional media (paper brochures were distributed to each home). Another municipality, for instance, uses codified Twitter hashtags for a variety of different emergencies. In other contexts, informal communication systems are used to overcome the limitations of formal procedures, as is the case of WhatsApp groups aimed at reaching "influential mothers" in order to rapidly communicate that a prefect closed schools the following morning due to severe weather conditions.

Communicating with citizens: information-gathering

Information-gathering mainly occurs through dedicated emergency telephone numbers, which are mentioned by most of the respondents. In smaller towns, face-to-face contact also seems relevant: "They stop you when you are walking down the street, or they come to your home […] Being the mayor of a small town, there is no filter, you face confrontation every day" (Mun.).

Some respondents also mentioned gathering information through dedicated sections of the institutional website, email, or Facebook messages. Digital media are generally mentioned as tools for information-gathering with regard to minor emergencies, while for major emergencies, traditional channels are more relevant, with the sole exception of the two cases identified as *social media best practices.* In general terms, respondents' attitudes towards information gathered through social media is ambivalent; most of the respondents defined citizen-generated information as non-trustworthy, while others also underlined that emergency telephone numbers are managed by trained professionals who follow specific procedures in order to verify information and identify the caller. A minority of respondents, on the other hand, underlined the relevance of information gathered through social media:

> [Referring to a specific emergency that occurred some months earlier] many people provided us with information through social networks, mainly Facebook; we received several warnings about streets that were closed, electrical power that was down, trees that fell down, information we wouldn't have received otherwise, because we were experiencing communication issues, and we were not able to reach the affected areas. (Mun.)

Some of them also referred to specific practices and procedures, often established on an informal basis, that contribute to verifying information.

> We encourage citizens to use social [media], instead of calling the contact center…. During emergencies, we constantly monitor [the predefined hashtag], so that we can also detect people not using it in a proper way, in order to gather information that is of course subsequently verified. I wouldn't say that we don't trust citizen-generated information, but we need to verify it in order to prioritize. (Mun.)

Overall, the respondents' words highlight what could be defined as a *spectrum of engagement* with digital media, ranging from basic use of the institutional website (which also corresponds with legal requirements for Italian public institutions) to a *broadcast*-oriented attitude toward social media platforms to a more interactive usage, including information-gathering through social media.

Social media perception

Social media representations and perception are multifaceted. On the one hand, respondents following what we define as an *institutional* style seem to negatively emphasize the distance between what they perceive as the interactive and horizontal nature of social media platforms and the formal role of institutions; they perceive it as highly hierarchical, and often refer to citizens in patronizing terms. On the other hand, respondents adopting a *practical-professional* narrative style underline the positive role of social media, highlighting the strategies adopted in order to avoid the potential dangers of *hoaxes* and misinformation.

Among the users adopting a *practical-professional* attitude, the perceived advantages of social media seem to prevail over perceived disadvantages. Among such advantages, respondents mentioned time-effectiveness, defined as crucial in emergency contexts; others referred to a general "need to be up-to-date," or to the need to devote more attention to interaction with citizens, which is perceived as necessary in order to overcome the self-referentiality that has historically affected Italian public institutions.

> I believe this is also a better way of working for us, because public administrations are that. They are communication, if there is no communication with citizens, public administrations are just self-referential. (Pref.)

The perceived disadvantages of social media are related to three main areas, and prevail among respondents adopting an *institutional* attitude. More specifically, while some disadvantages are mentioned by both categories of respondents, those adopting an *institutional* attitude seem to merely address them as an issue; those adopting a *practical-professional* attitude, on the other hand, while recognizing such (potential) drawbacks, refer to specific strategies or tactics that allow to overcome such issues.

First, some respondents described a distance between what they perceive as the interactive, informal, and non-ruled nature of social media, and the formal role played by institutions. The need to follow official communication procedures is mainly underlined by representatives of prefectures, while local level politicians (mainly municipal council members) seem more oriented toward engaging in informal and interactive communication processes.

A second, relevant issue as perceived by the respondents is related to the potential spread of disinformation and misinformation; *hoaxes* were mentioned by several respondents.

> We can’t forget that the prefect is responsible for law and order. Therefore, misinformation… and hoaxes like “in half an hour an earthquake will occur” may severely hinder public security. Just consider the chance that people believing such news will leave their homes…. Or crowds can be formed, occupying the streets…; the prefect is responsible for law and order, solely responsible for law and order, primarily responsible for law and order…. The prefect needs to manage correct, honest, verified information…because misinformation could also cause law and order problems. (Pref.)

This excerpt is in accordance with what Rodriguez, Quarantelli and Dynes (2007) defined as a *command and control* approach toward emergency management, which considers the affected population in patronizing terms. While misinformation and hoaxes are mentioned by most of the respondents, those who adhere to a *practical-professional* narrative style seem to consider them from a different perspective, highlighting the strategies adopted to deal with them, having established specific verification procedures (asking for pictures, asking for further information, engaging in a constant dialogue with citizens, carefully checking user profiles, etc.).

A third issue is the perception that social media have recently turned into an arena for *hate speech*. According to several respondents, citizens seem to indulge in verbal aggression towards government institutions and public figures, making demands, which often cannot be fulfilled, in emergency situations. Consequently, some respondents seem to have changed their previously positive attitude toward social media interaction, often calling for increased social media literacy and overall etiquette.

> Earlier on, I believed that chatting on social media was extremely important in order to understand citizen behavior.… But I can tell you that… there are growing demands, which are often polemical…; there’s always someone telling you what you are supposed to do, and how. (CP.)

While underlining similar phenomena, respondents adopting a *practical-professional* attitude highlight that when engaging in a constant dialogue with citizens, such drawbacks can be overcome.

> Earlier on, people showed a cooperative attitude. Now, Facebook is really widespread, and people are more aggressive, or complaining. Well, when they notice that you interact, you provide them with answers… sometimes, they even say “well, I knew that I needed to turn to Facebook… to get an answer” …. But in the end, they say, “but I was speaking in general terms, I’m really thankful to the staff that manages this page, because….” (Mun.)

Overall, the two attitudes seem to play a role in framing users’ concerns about what they define as the disadvantages of social media. For instance, *hate speech* is considered an issue by both categories of respondents: on the one hand, respondents adopting an *institutional* attitude mainly motivate their concerns highlighting that *hate speech* defames institutions; on the other hand, respondents adopting a *practical-professional* attitude are mainly concerned by the fact that *hate speech* might break shared communication etiquettes, and also underline the ways in which such issues can be overcome.

Barriers to social media usage

According to the respondents, the barriers to a broader social media adoption for spreading or gathering emergency-related information are multifaceted. Even if the interview outline explicitly referred to emergency situations, some of the respondents provided answers that apply to social media usage in more general terms.

Barriers that exist in peaceful times are likely to become even bigger in case of an emergency.

Organizational issues, as well as the lack of personnel (quantity and quality), are mentioned by most of the respondents when they focus both on peaceful times and on emergencies. The lack of resources is addressed as a general issue affecting Italian public institutions, while answers vary in the accuracy of their description. For instance, respondents adopting an *institutional* attitude tend to mention a generic lack of resources, while those adopting a *practical-professional* attitude provide more specific analyses. They mention issues in interacting with other offices in the same administration who follow more traditional practices. For instance, a social media manager underlines that “the other offices answer me by sending a PDF document” (Mun.). Some others highlight the lack of social media skills and expertise among public servants, calling for specific educational processes, or for hiring dedicated professionals. Technical resources, or the lack thereof, on the other hand, are not addressed as a relevant barrier, other than a single mention about the lack of broadband connectivity.

In general terms, several respondents refer to *cultural dimensions*, underlining that most administrative procedures are far from the speed and interactivity supported by social media. Moreover, among the barriers, some respondents refer to citizens, underlining their *cultural gaps*, or their old age. The relation between “non-use” (or “basic use”) and “barriers” does not appear to be linear; do barriers determine non-use (or basic use)? Or are the issues experienced in social media usage justified by respondents through the reference to perceived barriers? Indeed, respondents who underline citizen’ inadequacies are generally those who use social media only at basic levels, and who adopt an *institutional* attitude, while those who are more actively engaged with social media seem to be familiar with several strategies to overcome such barriers. Such dynamics seem to apply to other kind of barriers as well.

Another relevant barrier, for instance, is related to the lack of legislation regarding the ways that public institutions use social media. While the respondents who adopt an *institutional* attitude seem to consider the lack of regulation as a sufficient reason for not broadly using social media in emergency communication, waiting for “governmental authorization.” Those who adopt a *practical-professional* attitude mention some regulatory issues, without considering them enough to limit their usage. The latter, for instance, address more specific regulatory issues, including the prohibition to rely on (paid) social media advertising, or the lack of a formal recognition of the professional role of the social media manager. Indeed, institutional social media communication is generally the result of individual initiative, while only one respondent’s job description explicitly mentions his role as a “social media manager.”

Furthermore, another main barrier, which is mainly emphasized by those respondents who adopt an *institutional* attitude, is related to the abovementioned distance between the traditional role of institutions, and the perceived interactive and informal nature of social media. On the one hand, some respondents underline social media communication’s ephemeral nature, which has no legal validity, while administrations normally produce legally-binding acts.

> We are a public institution, we cannot produce legally-binding acts through social media. They help to rapidly reach our public, but we still need to follow more formal channels. Our activity is based on formal acts, even during emergencies. (Pref.)

Other respondents underline the difference between the unidirectional communication style adopted by administrations, and the interactive style, which is widespread on social media.

> I believe that institutional information, Facebook and Twitter, for instance, should be spread through an official channel, it should not allow the user to comment, in my opinion, because it is an official channel. [My personal profile] is a different channel, it’s personal, and therefore people are allowed to comment, but the official channel, in my opinion, should be different; it should provide information to the public. “Tomorrow XY street is closed. Period.” Why would someone wish to reply to something like that? […] You don’t need to comment on everything. (Mun.)

Some respondents, moreover, mention the fact that most social media platforms are proprietary, and do not show any collaborative attitude towards (Italian) institutions, but are completely focused on their commercial business.

Even if only a few of the respondents broadly adopt social media in order to gather emergency-related information, additional, specific barriers are mentioned in this regard by all of the respondents. The main barrier is related to the perceived low-trustworthiness of citizen-generated information. As already discussed, this seems to be the reason for avoiding gathering information through social media; some administrations do not use social media for this task, while other administrations have adopted specific procedures to overcome this barrier. Other respondents also mention organizational issues; even when gathering citizen-generated information, the lack of cooperation between different offices represents a major barrier for effectively employing such information in emergency management processes.

In general terms, while respondents adopting an *institutional* attitude seem to mainly underline the inadequacies of social media (that do not 'fit' the official role of institutions), those who adopt a *practical-professional* attitude stress institutions' inadequacies (underlining the organizational or legislative barriers that limit a broader social media usage).

Respondents' *desiderata*

Most of the respondents do not seem to have clear opinions about platform features or organizational issues in order to achieve more effective social media usage in emergency communication. Respondents' desiderata, albeit being mostly generic, can be divided into two main categories: organization-related, and platform-related. With regard to organizational aspects, several respondents refer to the wish to enhance dedicated human resources, and a broader collaboration between different offices belonging to the same institution. Some of the respondents, furthermore, refer to the need for a cultural change inside institutions. One of the respondents, moreover, wishes to have the chance to rely on (paid) social media advertising, a practice that is currently prohibited.

Only a few of the respondents expressed platform-specific *desiderata*, mentioning the following: enhancing geolocalization services, enhancing conversation-monitoring tools, and obtaining a "certified account" on social media platforms (which appears to be an issue for several Italian institutions). A respondent also mentioned the wish to introduce *social sensing* applications based on social media conversations, while another would like the general adoption of a codified hashtag for emergencies.

LIMITATIONS, FURTHER RESEARCH DIRECTIONS AND CONCLUSION

This paper explored the use of social media in emergency communication by Italian officers operating at a local level, focusing on social media usage patterns, social media perceptions and the barriers to broader social media adoption.

In our opinion, the main limitation of this research is that we performed a limited number of interviews (16) and that the main focus was devoted to a single region, which can be considered as the national average with regard to social media emergency communication. Nevertheless, considering the complex nature of the Italian civil protection system, as well as the fact that literature on this specific topic, analyzing the Italian context, is missing, we are convinced that exploring motivations, perceptions and representations constitutes a relevant step for a deeper understanding of the phenomenon. This research, moreover, represents the first step of a broader research project; we are currently involved in a quantitative study targeting officers operating at a local level in the whole country. In building the survey designed for the latter project, we strongly rely on the results of this qualitative research.

In designing the research project discussed in the previous pages, we were inspired by the work by Hiltz, Kushma and Plotnick (2014), and Plotnick, Hiltz, Kushma and Tapia (2015). These authors highlighted the main barriers to social media usage experienced by local level emergency managers operating in the US: lack of staff (quantity); lack of formal social media policies; lack of staff (skills); and low reliance on the trustworthiness of user-generated content.

Our research highlighted two main attitudes in respondents' answers, with regard both to the narrative style and social media representations. Some respondents seem to adopt an *institutional* attitude, while others adopt a *practical–professional* attitude. Such attitudes seem to be related to the ways in which respondents understand and use social media and will be further explored in the following steps of the research.

Our analysis highlighted a multifaceted picture with regard to social media usage both in institutional communication, in broader terms, and in emergency communication. Most of the institutions seem to rely mainly on traditional communication tools and practices, and social media usage is still uneven. When considering the few cases described in terms of *social media best practices,* experimentation with advanced forms of social media emergency communication seems to rely on individual activism, rather than on well-established policies. Among the main barriers to a broader adoption of social media for emergency communication, organizational issues, as well as a lack of resources, are mentioned by most of the respondents, along with concerns regarding social media communication reliability. In broader terms, *cultural* considerations seem to prevail; several respondents underline the perceived distance between the traditional role of institutions, and the interactive and informal nature of social media, while some also highlight that institutions need to produce legally-binding acts, which should not be questioned by citizens.

In this regard, Sutton et al. (2013) observed that citizens generally turn to social media to fill the information gap when institutions adopt a traditional *command and control* approach (Rodriguez et al., 2007), limiting the amount of information shared with citizens. Respondents seem aware that social media can enable organizational change, as well as a change in the relations with citizens, which could increasingly emphasize citizens' roles as *active survivors* (Rodriguez et al., 2007).

ACKNOWLEDGMENTS

This research is a part of the PRIN project "SHAKEnetworks", funded by MIUR (Italian Ministry of Education and Research).
We are grateful to Starr Roxanne Hiltz and Linda Plotnick for inspiring this work and for their insightful comments.

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Public expectations of social media use by critical infrastructure operators in crisis communication

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ABSTRACT

Previous research into the role of social media in crisis communication has tended to focus on how sites such as Twitter are used by emergency managers rather than other key stakeholders, such as critical infrastructure (CI) operators. This paper adds to this emergent field by empirically investigating public expectations of information provided by CI operators during crisis situations. It does so by drawing on key themes that emerged from a review of the literature on public expectations of disaster related information shared via social media, and presenting the results of an online questionnaire-based study of disaster-vulnerable communities in France, Norway, Portugal and Sweden. Results indicate that members of the public expect CI operators to provide disaster related information via traditional and social media and to respond to their queries on social media. CI operators should avail of the opportunities provided by social media to provide real-time information to disaster affected communities.

Keywords

Social media; traditional media; crisis communication; critical infrastructure operators; public expectations.

INTRODUCTION

Effective crisis communication can be defined as "the provision of effective and efficient messages to relevant audiences during the course of a crisis process" (Freberg et al., 2013:186). Large scale incidents such as the Mumbai terrorist attacks in November 2008 and the Haiti earthquake in January 2010 marked a watershed in the use of social media for sharing disaster information (Potts, 2014). Social media is the collection of software that enables individuals and communities to gather, communicate, share and in some cases collaborate or play (boyd, 2009). Some well-known examples include Facebook and Twitter. Twitter in particular has been increasingly used by emergency managers as a tool for crowdsourcing crisis information that helps build situational awareness during such incidents (Latonero and Shvlovski, 2010). This has led to the development of a series of guidelines for blue light organisations, such as police, firefighters, rescue services, etc. who use blue light sirens, as well as emergency managers on how best to use social media as a tool for crisis communication[1]. Previous research in this emergent area has tended to focus solely upon how these actors use social media for emergency management (Reuter et al., 2016; Bruns et al., 2012; The American Red Cross, 2009), often overlooking the role

[1] See for example, EU projects DRIVER, CascEff, or COSMIC guidelines; Belgium Federal Interior Minister white paper (http://centredecrise.be/sites/default/files/brochure_sociale_media_fr.pdf) or the French Ministry of Interior's crises communication kits destined for Prefectures (http://www.interieur.gouv.fr/Actualites/L-actu-du-Ministere/Votre-prefecture-presente-sur-les-reseaux-sociaux).

played by other key stakeholders such as critical infrastructure[2] (CI) operators. CI operators are the actors who are in charge of the critical infrastructure. In addition, there have also been few empirical studies (Reuter, 2015) exploring public expectations of information shared by CI operators during crisis situations. Indeed Reuter (2015) examined public information needs from energy operators during a blackout and found that the reason for and the expected duration of a power outage are of great interest to the public and that CI operators should make their information available for smart phones. However the work focused on the development of a smartphone application and had a relatively small sample size (12). Hence, this paper addresses these under-researched issues by drawing on key themes that emerged from a review of the literature on public expectations of disaster related information shared via social media, which is presented in the following section. Then the methodology and the results of an online questionnaire-based study of disaster-vulnerable communities in France, Norway, Portugal and Sweden are described. Afterwards, the findings are discussed with regard to social media use by CI operators during disasters. It concludes by proposing a number of recommendations for how CI operators can use social media to communicate with members of the public during crisis situations.

PUBLIC EXPECTATIONS OF DISASTER RELATED INFORMATION ON SOCIAL MEDIA

Types of information

Members of the public expect to be kept informed about the threat to their lives and properties at each stage of the disaster cycle (Perko et at., 2013; Tierney, 2009). They expect to be able to find out what has happened, what is expected to happen, and what steps they should take to mitigate the risk to themselves and their homes (Ryan, 2012). For example, after the Nepal earthquake in 2015, a survey of *LastQuake* app users conducted by the European Mediterranean Seismological Centre (EMSC) found that 44% of respondents wanted to be provided with “Dos and Don’ts”, in order for them to understand how to act after an earthquake (Bossu et al., 2015). People also expect to receive information written in a language that is jargon-free and easy to understand (Kaufman et al., 2012). This should also account for the different languages spoken by disaster affected communities. Delays in the evacuation of flood vulnerable areas in New Orleans during Hurricane Katrina in August 2005 were attributed to the fact that sections of the Spanish-speaking population had not heeded warnings, which had only been disseminated in English, despite US 2005 census data finding that one third of Spanish speakers speak English “less than well” (Jennings et al., 2013). Crisis communication should therefore be not only timely and accurate, but also tailored to the specific characteristics of the target population.

Social media and crisis situations

Social media has been identified as an increasingly important source of information that supports decision making processes during crisis situations. While there can be a considerable lag between the occurrence of a crisis situation and news reports about it, social media has been recognised for its potential to provide complementary and relevant information for crisis management in near real-time (Meier, 2013). That said, the public expect to receive crisis information from key stakeholders via both social and traditional media channels (The American Red Cross, 2009). Research has consistently shown that citizens seek information from whatever media channels are available to them during disasters, as was the case during large-scale incidents such as Hurricane Sandy and the 2011 Great East Japan Earthquake (Burger et al, 2013; Mitomo et al., 2013). Expectations about the availability of crisis information on social media have continued to rise over the past decade. A study commissioned by the American Red Cross (2009) found that sites such as Facebook and Twitter were the fourth most popular source of information during crisis situations. Subsequent surveys conducted in the European Union found that 43% of respondents used social media to look for information during a past emergency, with 58% stating that they would do so in the case of a future disaster (Reuter et al, 2016). During the 2011 Great East Japan Earthquake and Tsunami, more than half of Japanese citizens were said to have used sites such as Twitter to search for disaster-related information. Research suggested that 60% of non-affected individuals, 80% of indirectly affected individuals, and over 55% of directly affected individuals believed that the internet and social media were the most reliable information sources during the disaster (Takeuchi et al., 2012). As per the Reuter and Spielhofer (2016) survey, which found that 77% of respondents felt that crisis information was shared much more quickly online than via traditional media channels, social media appeared popular due to the ease with which these populations could search for and obtain information about the earthquake. Furthermore, both Facebook and Twitter were heavily used to find out information in Germany during the 2013 European Floods, with 157 Facebook pages and groups being created (Kaufhold et al.,

[2] The European Union defines CI as “an asset, system or part thereof that are essential for the health, safety, security, economic or social well-being of people, and its disruption or destruction would likely have a significant impact upon the ability of a Member State to maintain those functions (Council Directive, 2008).”

2016).

Social media use by authorities

There is already significant evidence to suggest that citizens are turning to the social media channels of emergency services to obtain information during crisis situations (Lindsay, 2011). During the 2010-11 Queensland floods, Queensland Police Service Media Unit used its Twitter account (@QPSMedia) to provide real-time information to those living in affected areas. Bruns et al. (2012) argued that this helped establish @QPSMedia as the most prominent and widely visited social media account for crisis information in Queensland. Furthermore, the public also expect a quick response if they contact blue light organisations via sites such as Facebook and Twitter. The American Red Cross survey (2009) found that 80% of respondents believed that emergency response organisations should monitor social media sites in order to respond quickly to calls for help. This resonated with the findings of the Reuter and Spielhofer (2016) survey, which suggested that 42% of European citizens expect emergency services to respond within one hour of them posting for help on their social media sites.

Social media use by CI operators

In contrast to emergency management organisations, there remains relatively little empirical research exploring public expectations of information provided by CI operators during crisis situations. Self-evidently, citizens are likely to expect regular updates on progress towards the restoration of services provided by these operators. Hence, power companies are expected to provide customers with accurate information about power restoration in the wake of extreme weather events (Lacey, 2014). Some CI operators have already used social media to address the information needs of disaster-affected populations, as was seen when Hurricane Sandy made landfall near New Jersey in September 2012. New York's Metropolitan Transportation Authority (MTA) used its website, Facebook and Twitter accounts to post regular updates on service availability to its customers (Kaufman et al., 2012). Energy company Public Service Enterprise Group (PSE&G) also used Twitter to update the public about the daily locations of their tents and generators during the power outages that followed Sandy (Fine, 2013).

METHODOLOGY

Three research questions emerged from the literature reviewed above:

1) What do European citizens expect of CI operators in regards to information provision during crisis situations?

2) Are there any noticeable similarities/differences between public expectations based on demographic factors?

3) How can CI operators meet these expectations?

In order to investigate these questions, the EU Horizon 2020 project IMPROVER (Improved risk evaluation and implementation of resilience concepts to critical infrastructure) designed an online questionnaire-based study. Ethics approval was sought and obtained from the respective authorities prior to data being collected. The target population for the questionnaire was adults aged 18 years and over who were familiar with four IMPROVER Living Labs, or clustered regions of different types of infrastructure which provide specific services to a city or region. These were: Barreiro Municipal Water Network, Oresund Region, Oslo Harbour, and French transportation networks (roadways). In order to maximise the response rate, the questionnaire was translated into six languages (English, French, Danish, Swedish, Norwegian, and Portuguese) prior to its distribution. It was structured as follows: first, a brief description of the IMPROVER project was provided and participants were informed of their right to withdraw from the project at any time, as well as how all data would be handled during the project. For the purposes of this questionnaire, respondents were presented with the following definition of a disaster: "an event which has catastrophic consequences and significantly affects the quality, quantity, or availability of the service provided by the critical infrastructure." Second, a Likert scale was used to measure participants' expectations. Participants were asked two questions regarding information provision. The first asked, "During and immediately after a disaster, I expect critical infrastructure operators to provide me with information…" and presented four scenarios: via calling their telephone number, on their website, on their social media site and through traditional media e.g. interviews with television networks or the radio, press releases. The second asked, "During and immediately after a disaster, I expect critical infrastructure operators to respond to my questions and comments on their social media sites e.g. Twitter." The questionnaire also asked about the participants' demographics. Data from the questionnaire was collected between 28 March 2016 and 30 April 2016. The questionnaires were translated back into English at the data entry stage. The questionnaire was disseminated through the IMPROVER consortium partners' contacts as well as through the Living Labs.

Sample characteristics

The sample consisted of 403 respondents. Due to the dissemination method, this self-selected sample was not broadly representative (at least by age, sex, or education level) of the European population, nor those of the geographical locations from which participants were drawn. Sample characteristics showed that 57% of participants were male, 41% female, with 2% choosing not to answer that question. Most were highly educated, with 77% reporting that they have a university degree or higher qualification. Both young and old people appeared to be underrepresented in the study. Respondents aged 18-24 accounted for only 8% of the total sample, with only 16% identifying themselves as aged 55 years and above. While 26 nationalities responded, 88 percent of the questionnaire sample consisted of French, Norwegian, Portuguese or Swedish respondents. As such, comparisons depending on nationality were carried out only for these four nationalities. Given the nature of the questionnaire, it was no surprise that 90% of the participants stated that they used social media sites on a regular basis. Finally, respondents who used social media were asked to list a maximum of three sites that they used most frequently. Results showed that overwhelmingly Facebook was listed (91%), followed by Instagram and Twitter (21% and 20%, respectively) (see Figure 1).

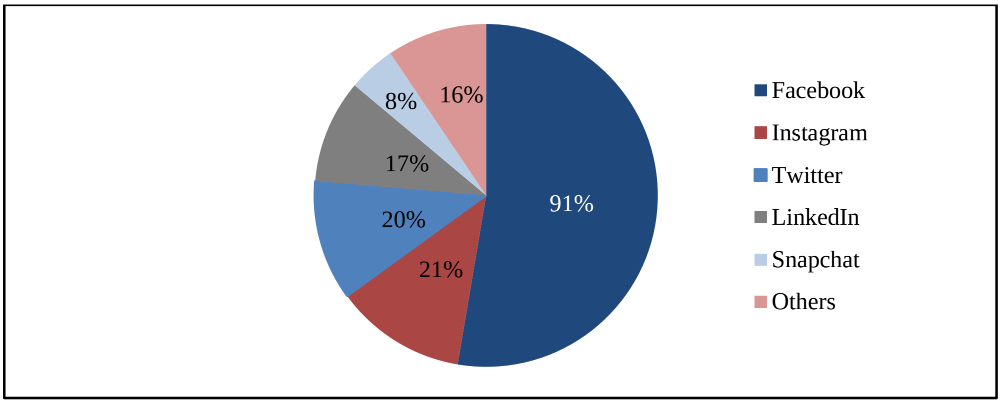

Figure 1 Respondents' most frequently used social media sites.

RESULTS

Every respondent expected CI operators to provide information during and immediately after a disaster via at least one media channel (telephone, social media, traditional media or website). CI operators were expected to use traditional broadcast media such as newspapers, radio or television to communicate with members of the public during such incidents, with 96% strongly agreeing or agreeing with this statement (see Figure 2). The majority of respondents (57% strongly agreed, 30% agreed) also had high expectations in relation to the availability of crisis information on the website of operators. Pertinent to this study, most agreed (49% strongly agreed, 25% agreed) with the proposition that CI operators should use social media for crisis communication, with 74% strongly agreeing or agreeing.

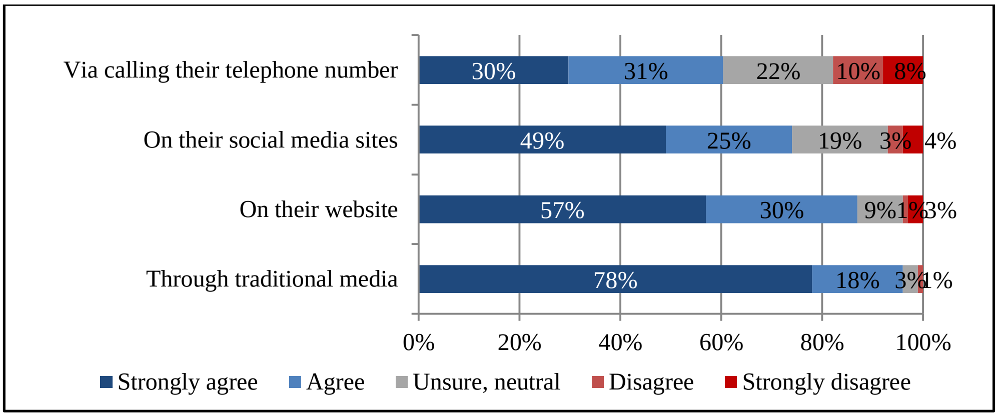

Figure 2 Respondents' expectations of information provision from CI operators during and after a disaster.

The study also found that expectations of information provided by CI operators during crisis situations varied according to different age groups, previous experience of social media use, and nationality. Social media was more popular among the youngest respondents, with 70% of 18-24 year olds strongly agreeing that they should be kept informed through sites such as Facebook and Twitter, compared to just 37% of those aged 55 years old and older. A similar finding emerged in relation to expectations that such information should be available on the website of CI operators. Those who declared that they were regular social media users were the most likely to expect to receive information from CI operators on these platforms. Indeed, 78% agreed or strongly agreed with this proposition, in comparison to only 29% of those who did not use social media sites. Social media non-users mostly (47%) declared that they are unsure or neutral. However, there appeared to be no significant differences between social media users and non-users in terms of their expectations of the other media channels.

There were some differences in terms of Portuguese respondents who had a higher expectation that information should be provided via a dedicated telephone line compared to respondents from other countries: 78% of Portuguese respondents agreed or strongly agreed with this proposition, compared to 67% of French, 59% of Norwegian and only 32% of Swedish respondents. In contrast, Portuguese respondents had lower expectations of obtaining such information via CI operators' websites. Conversely, there were no observable differences in terms of expectations of the media channels used by CI operators during crisis situations based on gender or educational level.

CI operators responsiveness to comments posted on their social media accounts

When asked if they expect CI operators to respond to questions and comments sent by members of the public to their social media accounts, there appeared to be greater uncertainty (see Figure 3). While one respondent out of two either agreed or strongly agreed, 25% were unsure about whether CI operators should respond on social media. No significant differences linked to sex, age, or education level were found in the responses to this particular question. Those who used social media (56% agreed or strongly agreed) were more likely to agree that CI operators should respond to these social media queries than non-users (32% agreed or strongly agreed). Although based on a small sample, the finding that Norwegian respondents were the least likely to agree with this proposition (36% compared to 51% of the Swedish, 61% of the French and 66% of the Portuguese respondents) merits further investigation.

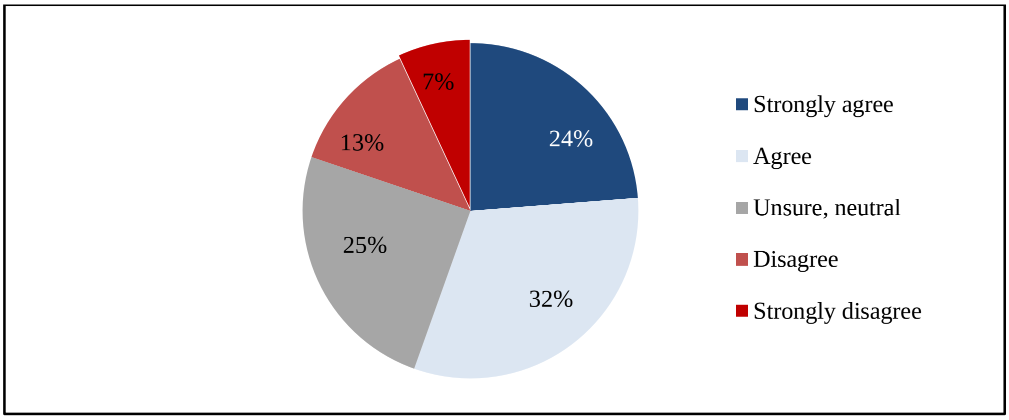

Figure 3 Respondents' expectations for two way communication on social media during and after a disaster.

DISCUSSION

Crisis information should be provided on social media but CI operators are not necessarily expected to engage with the public on these sites

Results indicate that members of the public expect CI operators to provide disaster related information via both traditional and social media. Social media should be considered a main channel for information dissemination, as 74% of respondents expect it. There appears to be a greater expectation for information to be pushed via social media (as only 7% of respondents disagreed or strongly disagreed with the proposal) than for queries to be answered (20% of respondents disagreed or strongly disagreed). Indeed, 25% of respondents were unsure about whether CI operators should respond to questions and comments on social media. Despite this, the high level of respondents who do expect CI operators to respond on social media (56%) demonstrates the importance of two-way communication. Since individuals turn to the media platforms that they are already familiar with during crisis (Fire Services Commissioner Victoria, 2013; Steelman et al., 2014), it seems natural that respondents who use social media have higher expectations for social media use by CI operators than social media non-users.

Some evidence of a 'digital divide' in relation to CI operators' use of internet and social media during crises

However, expectations were found to be influenced by age and nationality. Indeed, it would seem that the use of social media by CI operators is slightly more of a young person's expectation. Younger respondents also were more inclined to expect to find information on the CI operator's website, even though the senior respondents are all internet users, and 81% of respondents 45 years or older use social media. When it comes to nationality, one reason that Portuguese respondents have a higher expectation to get information via calling the CI telephone number could be because of the way in which the Portuguese questionnaire was disseminated (via the Barreiro municipality's Facebook Page). The Living Lab in Barreiro currently uses this method to provide information to the public, and does not have their own website or social media accounts. Another reason that Portuguese respondents seem to have lower expectations for website could be because Portugal has a lower Internet access by household rate and a less frequent Internet use than the other studied countries[3] (Eurostat, 2015). However, the lack of such a difference for social media expectations between countries may indicate that the Portuguese Internet access hides a wider generation gap than in other countries (ibid) and this is mostly a young respondents' expectation. This suggests that whatever the country, young respondents expect to get information on social media.

Thus, social media could be used in such a way as to target and better reach young people during disasters. Indeed, more effective crisis communication uses targeted messages (Medford-Davis, 2014). It is important to keep in mind that while young people are more present on social media and have a higher expectation of social media use by CI operators, they are not the only ones. As social media is meant to compliment more traditional crisis communication methods and not replace them, it remains a useful way to reach even more people in times of crisis.

Limitations

The limitations of the study should be acknowledged in the interpretation of the results presented above. As discussed earlier, this was a self-selecting sample that was not representative of the demographics in the four respective Living Labs. While acknowledging that online questionnaires usually have lower response rates than those administered via paper, it should also be noted that the use of the website to distribute the questionnaire was likely to have skewed the sample in favour of those who used the internet and social media on a regular basis. The international aspect of the survey may also cause an inaccurate generalisation of the findings, as social and cultural backgrounds may create different meanings for the Likert scale (Boulan, 2015). Furthermore, people often respond to online surveys by providing snap judgments based on available information and may be influenced by emotional or contextual factors (Schwarz et al., 1999).

RECOMMENDATIONS FOR SOCIAL MEDIA USE BY CRITICAL INFRASTRUCTURE OPERATORS DURING AND IMMEDIATELY AFTER A DISASTER

While a number of guidelines for how blue light organisations can use social media during disasters have been published over the past decade, few seem to focus on how CI operators could use these platforms to contribute to disaster information flows. Here we present a brief look at our ongoing work to develop a social media communication guide for CI operators to deploy during crisis situations, based on the literature and questionnaire results. While the questionnaire results are not representative of Europe, and indeed differences were found depending on nationality, the literature on effective crisis communication should be applicable to all CI operators, regardless of country of residence. That said, a key part of effective crisis communication is to know your stakeholders and their expectations. As such, further research should be conducted to learn about expectations for other nationalities. The following sections describe how CI operators should attempt to meet the information needs of disaster vulnerable and affected communities. They should provide information on 1) what has happened, 2) what is expected to happen, and 3) what citizens should do to mitigate the effects of such incidents.

What has happened

Firstly, it is vital that CI operators publicly acknowledge the disruption to their service(s), even if no further information on their cause and likely resolution is known. It is also important for operators to inform members of the public that they are working to restore these services even if no new information is available at that time (Petersen et al. 2016).

[3] Percent of households with Internet access: Norway 97%, Sweden 91%, France 83%, Portugal 70%. Percent of individuals who used Internet in the last three months: Norway 97%, Sweden 91%, France 85%, Portugal 69%.

CI operators should also use functionalities such as the 'Retweet' on Twitter to share messages from official sources. Official sources include emergency services, incident managers and local authorities, whereas unofficial sources are most likely to consist of content posted by citizens. Studies have shown that such repetition of crisis information is more likely to convince people to take appropriate action to protect themselves and their communities from harm (Tierney, 2009; New Zealand, the Ministry of Civil Defense & Emergency Management, 2010; Stephens et al., 2013; Reilly et al., 2016). For example, recent research has shown how music festivals in Belgium repost or retweet content originally posted by local Police and other blue light organisations in the case of an incident (Reilly et al., 2016).

What is expected to happen

As soon as is possible, CI operators should provide an estimate of when services will be fully restored. During Hurricane Sandy, for instance, customers became increasingly frustrated when power companies refused or were unwilling to give them an accurate timeline for restoration of electricity and other key utilities in affected areas (Pramaggiore, 2014). While it is beyond the scope of this paper to explore these strategies in full, Reilly and Atanasova (2016) suggest that social media can help key stakeholders such as CI operators prevent a communication vacuum from developing while simultaneously preventing cascading effects that might occur from citizen speculation about the causes and effects of crisis situations.

What citizens should do to mitigate the effects of incidents

As previously stated, when a disaster strikes, people begin a search for information about how they should act. As such, it is a good opportunity to provide the public with appropriate, CI specific advice, such as to, if conditions are safe, turn off the gas before leaving the house after an earthquake. While currently several CI operators have disaster preparedness sections on their websites[4], it is important to repeat this information during crisis events to disaster affected communities to help them to take appropriate action (Petersen et al., 2016). An example that could be replicated by CI operators could be the EMSC Safety Tips. Following their survey, the EMSC created cartoon images of the main messages of the behavior to adopt and avoid after a violent shaking no matter the country of residence, which is pushed to users of their app in a given location when violent shaking has occurred near them.

How to provide the information

As discussed earlier, it is important to provide information in a language people can understand, especially in a European context where many languages are spoken. Indeed, during Hurricane Sandy, CI operators were criticised for providing information about evacuation using public transport exclusively in English, whether on the website or social media (Kaufman et al., 2012).

CI operators should make a point of responding to the public via social media. It is especially important to respond on social media, as it generally encourages interaction and dialogue between users, creating information space that is essentially decentralized and devoid of hierarchy (Giroux, 2013). Not only would this help to meet public expectations, but also research shows that synchronous (where you can respond) messages are more effective in eliciting action during an urgent situation, making for more effective crisis communication (Stephens et al., 2013). Two-way communication has also been found to be fundamental to building trust and local impact (McDonald, 2016).

As previously stated, people continue to use media they are already familiar with during disasters (Fire Services Commissioner Victoria, 2013; Steelman et al., 2014). Based on the questionnaire results, it is highly recommended that CI operators be present on Facebook.

CONCLUSION

Our findings suggest that CI operators should continue to use traditional media during crisis situations, as almost all respondents expect to be able to find information through this means. This should be supplemented through the provision of disaster related information on website and social media platforms maintained by CI operators. Websites were identified by our participants as particularly important channels for such information. However, there was also an expectation that CI operators should provide this information for members of the

[4] See SoCalGas (https://www.socalgas.com/stay-safe/emergency-information/emergency-preparedness), PG&E (https://www.pge.com/en_US/safety/emergency-preparedness/emergency-preparedness.page), or SDGE (http://www.sdge.com/safety/electric/case-accident-involving-electric-line).

public on their various social media platforms. Young people and social media users appear to have higher expectations in regards to the use of social media by CI operators in times of crises. As social media is meant to compliment more traditional crisis communication methods and not replace them, it remains a useful way to reach even more people in times of crisis. The expectation to be on social media did not necessarily mean that sites such as Facebook and Twitter should be used to encourage dialogue and interaction between these companies and members of the public. Indeed, there appeared to be a greater demand for information to be pushed via social media than for queries to be answered during such incidents. While over half of respondents believed that there should be some two-way communication via these sites, a sizeable minority (25%) were unsure if CI operators should be responding to online queries. Nevertheless, it should be acknowledged that this was a self-selecting sample that was not representative of the demographics in the populations studied, and as it was an online questionnaire it most likely attracted people who generally use the Internet and social media. Further work is needed to explore how the perspectives of citizens who are unable or unwilling to use digital media.

Based on these findings, recommendations for social media use by CI operators during and immediately after a disaster were presented. CI operators should communicate on social media about 1) what has happened, 2) what is expected to happen, and 3) what to do. Furthermore, they should acknowledge when there has been a disruption; provide estimations for service restoration times; repeat official disaster information from official sources; give infrastructure specific advice; and respond to the public in a language they understand. Future work will consider the implications of these findings for CI operators and efforts to build community disaster resilience within these Living Labs. A communication strategy, encompassing both digital and traditional media platforms, will be developed for CI operators to deploy during each stage of the incident.

ACKNOWLDEGEMENTS

The IMPROVER project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653390.

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A Framework of Quality Assessment Methods for Crowdsourced Geographic Information: a Systematic Literature Review

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ABSTRACT

Crowdsourced Geographic Information (CGI) has emerged as a potential source of geographic information in different application domains. Despite the advantages associated with it, this information lacks quality assurance, since it is provided by different people. Therefore, several authors have started investigating different methods to assess the quality of CGI. Some of the existing methods have been summarized in different classification scheme. However, there is not an overview of the methods employed to assess the quality of CGI in the absence of authoritative data. On the basis of a systematic literature review, we found 13 methods that can be employed to this end.

Keywords

Volunteered Geographic Information, VGI, Crowdsourced Geographic Information, Quality Assessment, Systematic Literature Review.

INTRODUCTION

The use of Crowdsourced Geographic Information (CGI) has grown in the past few years owing to a number of key features, e.g. it is free, up-to-date and provided by several volunteers. CGI is an umbrella term that encompasses both "active/conscious" and "passive/unconscious" georeferenced information (See et al., 2016). This term has been used as an equivalent of Volunteered Geographic Information (VGI) (Goodchild, 2007) since some researchers have questioned the use of the term "volunteered" to refer to information that is collected without the will or conscious knowledge of the provider (Harvey, 2013). VGI is georeferenced information that is produced by volunteers using appropriate tools like Web portals and mobile devices (Goodchild, 2007). This type of information can be obtained through three collaborative activities: (*i*) social media, (*ii*) crowd sensing and (*iii*) collaborative mapping (Albuquerque, Herfort, Eckle, & Zipf, 2016).

When making use of CGI, ensuring the quality of the information is a challenging question. The information that is supplied by volunteers does not have to comply with any quality standards, and there is no control of the creation process. In addition, most volunteers do not have any formal training or cartographic skills. It is thus becoming increasingly important to assess the quality of CGI before it is used. Quality assessment is an important step to understanding if the information is fit-for-purpose with regard to the way it will be used (Ballatore & Zipf, 2015).

Several researchers have started investigating different approaches to assess the quality of CGI. Currently, there are a large number of methods to accomplish this task (e.g. Foody et al., 2013; Girres & Touya, 2010). These methods differ with regard to the type of information evaluated, and reference data types, among other factors. Owing to the large number of existing methods, selecting one is not a trivial task.

In an attempt to summarize these methods, several researchers have reviewed and categorized them in the literature (Bordogna et al., 2016; Mirbabaie et al., 2016; Senaratne et al., 2017; Wiggins et al., 2011). They have sought to answer questions such as the following: What are the methods used to assess the quality of CGI in Citizen Science projects? What are the methods to assess the quality of map-, image-, and text-based CGI? However, a question still remains. What are the methods used to assess the quality of CGI in the absence of authoritative data? This is important since authoritative data may not be available or may be out-of-date. Authoritative data are ground-truth data that are provided by official and trustable sources.

In this work, we address this question by carrying out a Systematic Literature Review (SLR) to discover the existing methods to assess the quality of CGI when authoritative data is not available. This SLR aims at providing an overview of the characteristics of the existing methods for researchers and developers of crowdsourcing-based platforms. Additionally, this work can be used to identify where further investigation is still needed.

The remainder of this article is structured as follows. In Section 2, we examine the quality of CGI. In Section 3, there is an overview of related works. In Section 4, the methodology employed for carrying out the SLR. Following this, each method is outlined in detail in Section 5. In Section 6, we discuss and summarize our findings and the limitations of our SLR, and make suggestions for future research.

QUALITY OF CGI

When dealing with crowdsourced geographic information, concerns arise regarding its quality and value as an information source. The quality of CGI largely depends on different factors such as the characteristics of the volunteer, the type of information, and the way in which the information is produced (Bordogna et al., 2016).

CGI is provided by a wide range of sources (e.g. volunteers), who have different levels of expertise and come from different backgrounds. There are several reasons for supplying information and heterogeneous methods for interpreting and communicating it. Volunteers are responsible for providing types of information that are characterized by a lack of structure, since it is collected by several crowdsourcing platforms with heterogeneous media formats and interface options. Furthermore, this kind of information is produced without a standard process. A combination of these factors leads to heterogeneous quality, which can affect the usability of the crowdsourced information (Bishr & Kuhn, 2013). However, the effects of its quality depends on how the information is used (Goodchild & Glennon, 2010), since the quality of the information is determined by the context in which it is applied (Bordogna et al., 2016). Depending on the context, the quality of CGI may be a serious factor (Goodchild & Glennon, 2010). Hence, a knowledge of the degree of quality allows people to use the information with confidence or may warn them of potential risks (Jilani et al., 2014).

The quality of CGI can be measured by means of distinct elements. A "quality element" is a component that describes an aspect of the quality of geographic information (ISO, 2013). The International Organization for Standardization (ISO) defines a set of quality elements that can be used to measure the quality of geographic information, i.e. completeness, positional accuracy, thematic accuracy, logical consistency, temporal quality and usability.

These quality elements are used to measure the quality of CGI. However, this type of information has specific features which makes conducting a quality assessment different from the case of traditional geographic data (Mohammadi & Malek, 2015). Hence, researchers have added new elements to measure CGI quality, such as trust, or made new definitions for existing quality elements, which can be measured by different methods (see the description in Section 5). They are characterized in line with (i) the approach adopted (i.e., geographic, crowdsourcing, and social); (ii) the type of reference data, i.e. intrinsic or extrinsic; and (iii) the temporality of the method (ex ante vs. ex post). Each category is described in the following sections.

Approaches for quality assessment of CGI

Goodchild & Li (2012) proposed three approaches to assess CGI quality: (i) crowdsourcing, (ii) social and (iii) geographic. The crowdsourcing approach is based on the ability of a group to detect and correct possible mistakes made by an individual. In OpenStreetMap, for example, it is possible to edit and correct erroneous geographic features provided by other people.

In the social approach, people at a higher level in the hierarchy act as gatekeepers of crowdsourcing platforms. Thus, a group of people can maintain the integrity of the platform, prevent vandalism and copyright protected material, and avoid abusive content. In the Flood Citizen Observatory (Degrossi et al., 2014), for instance, the platform administrator acts as a gatekeeper, by assessing the veracity of CGI and classifying it as checked or unchecked.

Finally, in the geographic approach, CGI is compared with a geographic dataset. This approach is based on the First Law of Geography, where "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). Thus, a geographic information is more related to the geographic context of that area consistent with it historical facts. Albuquerque et al. (2014) showed, for instance, that when the overall number of flood-related tweets are compared, "there is perhaps a tendency for 'relevant' on-topic tweets to be closer to flood-affected catchments".

Reference Data

Depending on which reference dataset is used, methods for quality assessment can be classified as either extrinsic or intrinsic. Extrinsic methods use external knowledge to measure the quality of CGI. Although authoritative data are commonly used as external knowledge, their use can be constrained by financial costs, licensing restrictions (Mooney et al., 2010), and currency (Goodchild & Li, 2012).

Intrinsic methods do not rely on external knowledge for assessing the quality of CGI. Despite this, these methods are employed to analyze historical metadata as a means of inferring the inherent quality of the data. Thus, it is possible to evaluate the quality of CGI regardless of whether a reference dataset is available or not. However, in some cases, intrinsic methods do not allow absolute statements to be made about CGI quality. Thus, they can only be used for making rough estimates of the possible data quality (Barron et al., 2014).

Temporality

The assessment of the quality of CGI can be carried out in light of two temporalities: (i) ex ante and (ii) ex post (Bordogna et al., 2016). These differ with regard to the time when the assessment is carried out compared with the creation time of CGI. The *Ex ante* strategy is employed before a CGI is created and seeks to avoid the creation of low-quality CGI (Bordogna et al., 2016). As well as offering mechanisms for controlling data creation, these methods also provide volunteers with resources for guiding the way information is produced. In contrast, the *Ex post* strategy is employed after a CGI item has been created. This strategy aims at removing and improving CGI quality. This involves first checking the quality of CGI and, later, filtering it.

RELATED WORKS

The quality of CGI has become a very popular topic amongst academics and researchers (Antoniou & Skopeliti, 2015). Several critical literature reviews (or surveys) involving categorization have been conducted to provide an overview of this area (e.g. Bordogna et al., 2016; Mirbabaie et al., 2016; Senaratne et al., 2017; Wiggins et al., 2011).

An analysis of the quality assessment methods was carried out by Wiggins et al. (2011), where the authors analyzed the data validation policy and quality assessment in Citizen Science projects (i.e., Participatory Sensing). They found that the most common type of data validation is ex post, which is based on expert reviews conducted by trusted individuals or moderators. Bordogna et al. (2016) have also analyzed CGI in Citizen Science projects. They initially reviewed and categorized CGI projects, by analyzing the way they deal with CGI quality. This work also provided a classification scheme and a critical description of the strategies currently adopted to improve CGI quality. Bordogna et al. (2016) and Wiggins et al. (2011) conducted an important overview of quality assessment methods and made significant recommendations for improving CGI quality during a research project. However, these authors only discuss methods for quality assessment of CGI in Citizen Science projects and fail to take account of other CGI sources such as Collaborative Mapping and Social Media.

Senaratne et al. (2017) conducted a critical literature review of the existing methods to assess the quality of the main types of CGI: text, image, and map. This review examines methods that are based on theories and discussions in the literature, and provides examples of the practical applicability of all the different approaches. However, this is a traditional literature review and, as many researchers have pointed out, traditional reviews are prone to bias, i.e., authors may decide only to include studies with which they are familiar or which support their particular standpoint. In an attempt to avoid this kind of bias, we conducted a systematic literature review (SLR) to discover the methods employed to assess the quality of CGI. An SLR adopts a replicable, scientific, and transparent approach to locate the most significant literature about a given topic or discipline.

Mirbabaie et al. (2016) conducted a systematic literature review on CGI in disaster management. The main goal of this review was to provide information about the quality elements that are used, as well as the methods that are employed to measure these elements. They found that attributes such as ‘accuracy’ and ‘consistency’ are mainly used as criteria for quality assessment, while other factors such as ‘trustworthiness’ are not fully taken into account. However, they failed to conduct an in-depth analysis of the existing methods with regard to their applications and limitations and were only concerned with the existing methods for disaster management. To fill this gap, we carried out an SLR to discover the existing quality assessment methods for CGI in different application domains and discussed the limitations of each method.

METHODOLOGY

Systematic Literature Review (SLR) was first applied to support evidence-based medicine. SLR is a kind of secondary study that aims at identifying, analyzing and interpreting all the available evidence related to a research topic (Kitchenham & Charters, 2007). Differently from the usual process of literature review, a SLR is undertaken in a formal, rigorous and systematic way (Biolchini et al. 2005; Okoli & Schabram, 2010), i.e. in a way that is unbiased and (in a certain degree) repeatable (Kitchenham & Charters, 2007). With this methodology is possible to summarize existing evidence and identify any gaps in a research topic, and provide a framework for position new research activities (Kitchenham & Charters, 2007). Recently, SLR has been applied to the field of Geographic Information Science (GIS) for analyzing the current state of research, for instance, on the use of CGI for disaster management (Horita et al. 2013); concerning methodologies application and use cases of Twitter as a Location-based Social Network (Steiger et al. 2015); and on the use of CGI within natural hazard analysis (Klonner et al. 2016).

In this work, an SLR was carried out to discover current research on CGI within the scope of quality assessment. More specifically, each study was analyzed with regard to the method designed for assessing the quality of CGI. In conducting the SLR, we complied with the guidelines recommended by Kitchenham & Charters (2007). The SLR follows a sequence of well-defined steps, which comprises (i) planning the review, (ii) conducting the review and (iii) reporting the review.

Review Planning

An important activity of the planning phase is to draft a clear and concise Research Question (RQ) (Brereton et al., 2007; Okoli & Schabram, 2010), since it will be used as a guide for the entire SLR process. As the main goal of this work is to discover studies proposing methods for the quality assessment of CGI, the following RQ has been raised:

RQ) What are the methods used to assess the quality of CGI?

In a SLR, existing evidence to answer a RQ can be obtained by carrying out a search string on electronic databases. To build the search string, we first selected the main terms of our RQ, i.e. crowdsourced geographic information and quality assessment. We also identified synonyms for each term in order to maximize the number of returned studies. The synonyms for the former term were extracted from See et al. (2016). We applied the Boolean operator OR to join the synonyms of each term and the Boolean operator AND to join the main terms. The search string is shown in Table 1.

The identification of studies began with the search string being applied to 5 (five) electronic databases (Table 2). We particularly selected this set of electronic databases in order to maximize the number of studies, since a single database cannot find all the existing evidence concerning a research topic (Brereton et al., 2007). Moreover, we selected this set because of their relevance to the research field, i.e. these electronic databases index the main journals and conferences of the area. However, owing to the idiosyncrasy of each electronic database, we had to adjust the search string to them since there were few relevant studies in this field. Hence, we had to remove some synonyms of the search string (e.g., social computing, quality analysis and quality enhancement).

The inclusion and exclusion criteria assisted the selection of key studies that could be used to answer the research question (Biolchini et al., 2005; Petersen et al., 2007). Considering the main goal of this SLR and the aforementioned RQ, we defined a set of inclusion and exclusion criteria (Table 3) that were used as a basis for the selection of studies. Besides this set, a study was also excluded if (i) it is not published between 2004 and November 2015, (ii) it is not written in Portuguese or English, (iii) it is a SLR, (iv) it is not available and (v) it is duplicated or incomplete.

Table 1. Search string

(VGI OR "volunteered geographic information" OR "volunteered geographic data" OR "crowdsourced geographic information" OR "crisis mapping" OR "collaborative mapping" OR OpenStreetMap OR ((crowdsourcing OR "crowd sourcing" OR "crowd-sourcing" OR "crowd-sourced data" OR "user-generated content" OR "social media" OR Twitter OR Flickr OR "collective intelligence" OR "collective knowledge" OR "citizen based") AND (geographic OR spatial OR geotagged OR georeferenced))) AND ("quality assessment" OR "quality assurance" OR "quality evaluation" OR "quality control" OR reliability OR credibility OR trust OR accuracy)

Table 2. Electronic databases

Electronic Database	URL
IEEE Xplore	www.ieeexplore.ieee.org
ACM Digital Library	www.portal.acm.org
Web of Science	www.webofknowledge.com
Science Direct	www.sciencedirect.com
SCOPUS	www.scopus.com

Table 3. The inclusion and exclusion criteria employed for the qualitative review

IC1: the study sets out or adopts an approach for the quality assessment of crowdsourced geographic information
EC1: the study is related to quality assessment, but not to crowdsourced geographic information
EC2: the study is related to crowdsourced geographic information, but not to quality assessment
EC3: the study is not related to crowdsourced geographic information or quality assessment

Review Results

The search in the electronic databases resulted in a total of 555 primary studies included, after the duplicate studies had been removed (Figure 1). After reading the title and abstract, we identified 501 studies that are not directly related to the quality assessment of CGI. However, if the objective of the work was not clear in the abstract, the study was included for a more in-depth analysis. After this stage, we included 54 studies for a complete reading.

While the complete reading, the included studies were analyzed to determine if the study was indeed a candidate to answer the RQ. If the study satisfies at least one exclusion criterion, this was excluded. However, if doubts emerged with regard to include the study; the opinion of another reviewer was taken into account to decide about it. After a close analysis, 18 studies were found that discuss methods for assessing CGI quality (Table 4). In the following section, we describe each method in detail.

QUALITY ASSESSMENT METHODS

In this section, we describe the existing methods for quality assessment of CGI in the absence of authoritative data.

Geographic Context

Description: Each place has its own distinguishing characteristics. The basic idea entails investigating the area surrounding the CGI location to determine its characteristics and, make an assessment of its quality. Both physical and human characteristics should be taken into account when undertaking this.

Example: Senaratne et al. (2013) examined the geographic context around Flickr photographs to determine which areas can be viewed from the CGI location, or more specifically, whether the object can be viewed from the CGI location. Similarly, Zielstra & Hochmair (2013) carried out an investigation to evaluate the positional accuracy of geotagged photos from Flickr and Panoramio.

Redundancy of volunteers' contribution

Description: This method involves requesting several volunteers to provide information about the same geographic feature. Later, the CGI quality is determined by analyzing the volunteers' contributions by finding out whether or not there is a convergence of the information produced independently by different volunteers. For example, a geographic feature is labeled by several people to indicate a part of the land cover. The resulting set of labels is then analyzed and there is an estimate of the probability that the geographic feature belongs to a land cover category.

Example: Comber et al. (2013) used redundancy to estimate the reliability of non-expert volunteers. Similarly, See et al. (2013) employed this method to evaluate the accuracy and consistency of volunteers when labeling land cover and determining the human impact on the environment. Foody et al. (2013) applied redundancy to measure the accuracy of each volunteer when labeling images of land cover from satellite sensors. In contrast, Foody (2013) explored the redundancy of contributions to situations in which a large proportion of data is provided by poor sources and/or is incomplete.

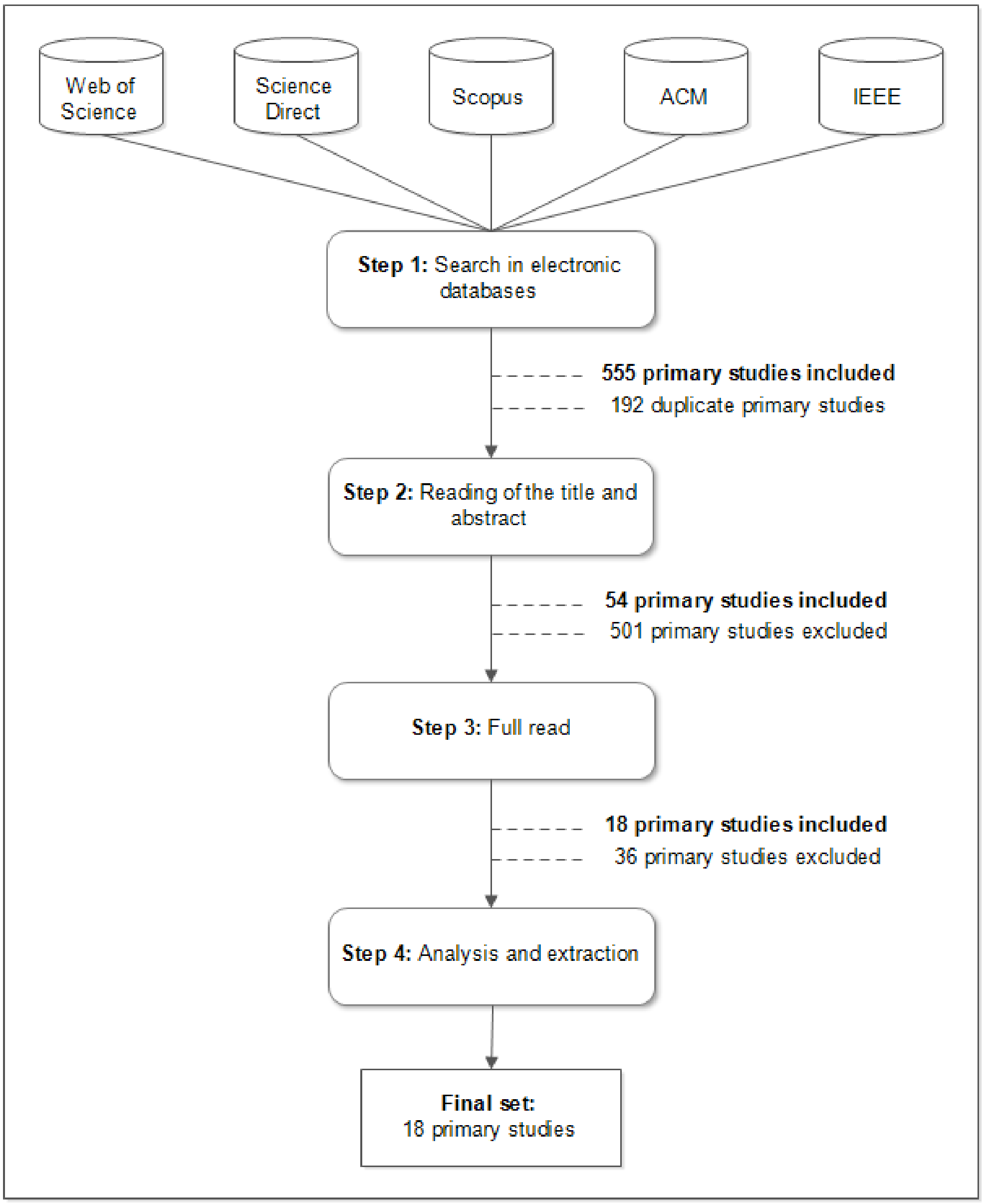

Figure 1. SLR process and the number of included and excluded studies in each step

Table 4. Detailed overview of the selected studies in the SLR

Study	Collaborative activity	Method	Quality element(s)	Objective
Karam & Melchiori (2013)	General	Ranking volunteers' contribution	Accuracy and completeness	Ranking volunteers' contribution to improve the accuracy and completeness of geo-spatial linked open data
Bordogna, Carrara, Criscuolo, Pepe, & Rampini (2014)	Participatory sensing	Ranking/filtering by linguistic terms	Fitness for purpose	Ranking and filtering high-quality CGI items in a glaciological citizen science project
Mohammadi & Malek (2015)	Collaborative mapping	Pattern extraction	Positional accuracy	Extracting patterns from corresponding reference data to estimate the positional accuracy of no corresponding reference OpenStreetMap data
Foody et al. (2013)	Participatory sensing	Redundancy of volunteers' contribution	Thematic accuracy	Employing redundancy of volunteers' contribution to evaluate the thematic accuracy of CGI
Cui (2013)	Participatory sensing	Automatic location checking	Spatial accuracy	Automatic checking of the positional accuracy of farmer markets' location
Jilani et al. (2014)	Collaborative mapping	Extraction/learning of characteristics	Semantic accuracy	Extraction and learning of geometrical and topological properties to assess the semantic accuracy of street network data from OpenStreetMap
Longueville et al. (2010)	Social media	Spatiotemporal clustering	Credibility	Spatiotemporal clustering of CGI items on social media to assess its credibility
See et al. (2013)	Participatory sensing	Redundancy of volunteers' contribution	Accuracy	Employing redundancy of volunteers' contribution to assess the accuracy of crowdsourced data on land cover
Ali & Schmid (2014)	Collaborative mapping	Data-based inference	Plausibility	Data-based inference to predict the correct class of a new entity in OpenStreetMap

Table 4. Detailed overview of the selected studies in the SLR

Study	Collaborative activity	Method	Quality element(s)	Objective
Haklay, Basiouka, Antoniou, & Ather (2010)	Collaborative mapping	Error detection/correct by crowd	Positional accuracy	Error detection and correction by crowd to improve positional accuracy of road network from OpenStreetMap
Bodnar et al. (2014)	Social media	Volunteer’s profile; reputation	Trustworthiness	Analyzing volunteer’s profile to determine the trustworthiness of his/her posts on social media
Zielstra & Hochmair (2013)	Social media	Geographic context	Positional accuracy	Analysis of the geographic context to evaluate the positional accuracy of Flickr and Panoramio photos
Foody (2013)	Participatory sensing	Redundancy of volunteers’ contribution	Thematic accuracy	Exploring the redundancy of volunteer’s contribution to assess the thematic accuracy of CGI in situations where a large proportion of data might come from spammers and/or be incomplete
Lertnattee et al. (2010)	Participatory sensing	Scoring volunteers' contribution	Reliability	Scoring CGI items in order to assess their reliability
Bishr & Kuhn (2013)	Participatory sensing	Volunteer’s profile; reputation	Trustworthiness	Analysis of volunteer’s reputation to evaluate CGI quality regarding the quality of water from a well
Keßler & de Groot (2013)	Collaborative mapping	Historical data analysis	Trustworthiness	Analysis of historical data to assess the trustworthiness of OpenStreetMap data in Muenster, Germany
Comber et al. (2013)	Participatory sensing	Redundancy of volunteers’ contribution	Reliability	Employing redundancy of volunteers’ contribution to determine the reliability of VGI with regard to the type of land cover
Senaratne et al. (2013)	Social Media	Geographic context	Positional accuracy	Analysis of the geographic context to assess the positional accuracy of Flickr photos

Scoring volunteers' contribution

Description: In crowdsourcing-based platforms, volunteers share their knowledge and opinions with the public. In this method, every contribution made by volunteers is awarded a score which is attached to the information. This score represents the "content quality" and it can be measured by means of different techniques.

Example: Lertnattee et al. (2010) measured the score by counting the number of votes, i.e. giving a voting score. Thus, information in a higher position in the hierarchy tends to be more believable by the users.

Ranking volunteers' contribution

Description: Feedback and contributions from other volunteers, that are familiar with an area, greatly assist in estimating the quality of CGI (Karam & Melchiori, 2013). In this method, CGI is submitted to experts who have more knowledge about the geographic area and are responsible for checking the quality of CGI and change, i.e. to correct it, if necessary. Later, all the CGI are ranked on the basis of the changes made by the experts and the historical record of activities carried out by a volunteer.

Example: Karam & Melchiori (2013) ranked CGI by employing four metrics: (i) the historical records of activities carried out by a volunteer, (ii) the number of activities carried out by other volunteers, (iii) the feedback received after the change was made and (iv) the scoring of the user that submitted the information.

Automatic location checking

Description: The location of a volunteer can be ascertained in different ways, such as GPS (Global Positioning System), manual georeferencing, or an address. However, the last of these could contain errors or typos. A way of automatically estimating it is to compare geocoded coordinates, from multiple geocoding services, with each other. Hence, the address should be submitted to several geocoding services, which will result in coordinates that are represented by latitude and longitude, and then provide the resulting address. To qualify as reference data, the different geocoding services should yield concordant results within a certain distance (Cui, 2013). The quality is, thus, measured as the distance between the geocoded coordinate and the actual coordinate.

Example: Cui (2013) employed automatic checking to determine the spatial accuracy of the location of a farmers' market.

Spatiotemporal clustering

Description: CGI quality can be addressed by aggregating information from several volunteers (Mummidi & Krumm, 2008) and, later, by evaluating the significance of the resulting clusters for a specific purpose (Longueville et al., 2010). Thus, instead of checking the quality of a single CGI element, the elements are evaluated as a whole, i.e. the quality of the CGI cluster is assessed.

This method consists of creating spatiotemporal clusters of CGI elements using prior information about a phenomenon of interest. The clusters are created on the basis of the assumption that "CGI elements created at the same place and time refer to the same event" (Longueville et al., 2010).

The process starts by creating temporal clusters, which are the CGI elements clustered in several temporal classes. After this, the temporal classes are divided into sub-classes in compliance with spatial criteria. These steps convert raw CGI of an unknown quality into spatiotemporal clusters, the importance of which can be quantified by means of a ranking score, which reflects the likelihood that an event took place in the time period and area that each cluster refers to.

Example: Longueville et al. (2010) clustered CGI to derive the likelihood that a flood event took place..

Volunteer's profile; reputation

Description: The volunteer is an important factor in the quality of CGI since his/her knowledge and background can have an influence on it. According to Fava (2015), for instance, expert volunteers provide higher-quality information than non-expert volunteers. Thus, they can act as a marker for the quality of their contributions. By employing this method, the volunteer's profile or reputation can be analyzed and used as a basis to estimate the quality of CGI. Bishr & Janowicz (2010) argue that if the volunteer has a reputation for being trustworthy; this means that his or her contribution is trustworthy too.

Example: Bodnar et al. (2014) employed this method to establish the veracity of four events, two of which turned out to be hoaxes, that took place in the United States. In contrast, Bishr & Kuhn (2013) employed this method to assess the trustworthiness of volunteers' statements regarding the quality of water from a well.

Error detection/correct by crowd

Description: According to Linus's Law, "given enough eyeballs, all bugs are shallow" (Raymond, 1999 *apud* Haklay, Basiouka, Antoniou, & Ather, 2010). In the case of CGI, this can be understood as 'given enough volunteers, (almost) all errors can be identified and corrected'.

The basic idea behind this method is that a single individual might unintentionally introduce an error in a crowdsourcing-based platform. Later, other people might notice this error and correct it, and hence the community of volunteers acts as gatekeepers.

Example: Haklay, Basiouka, Antoniou, & Ather (2010) investigated whether Linus's Law applies to the positional accuracy of OSM data.

Data-based inference

Description: Each geographic feature has its own characteristics (i.e. shape, size, etc.) which can be used to classify it. This method consists of learning the characteristics of each geographic feature and, later, using them to infer the correct type of a new entity. The inference is carried out by noting similarities with existing entities. The method can also be used to detect an incorrect classification of geographic features.

Example: Ali & Schmid (2014) designed a classifier that learns the correct class of existing entities (i.e. parks and gardens) on the basis of their characteristics (e.g. size) and used it to predict the correct class of a new entity.

Pattern extraction

Description: Assessing CGI quality without ground-truth data is a challenge. An alternative is to extract patterns from CGI with corresponding reference data and use the extracted pattern to estimate the quality of CGI without the need for a corresponding reference dataset. To achieve this goal, it is first necessary to define the indicators that can have an influence on the quality of CGI. Later, these can be used, together with the definition, to extract a pattern of the relation. Finally, the value of the defined indicators from the CGI with no corresponding dataset can be used with the patterns to estimate its quality.

Example: Mohammadi & Malek (2015) estimated the positional accuracy of no corresponding reference (NCR) OSM data by extracting a pattern from the corresponding reference (CR) OSM data.

Extraction/learning of characteristics

Description: Data representation can be regarded as the first stage towards knowledge discovery and allows the characteristics that are representative of each type of data to be extracted. Once the characteristics of a dataset have been obtained, the next stage entails learning the information implicit in the characteristics of the data.

Example: Jilani et al. (2014) extracted geometrical and topological properties of OSM street network data to infer the "road class" from the new data.

Ranking/filtering by linguistic terms

Description: The underlying principle of this method is the need to express the criteria linguistically. The linguistic terms are used to specify the desired values of the quality indicators and together, these comprise a schema for quality evaluation. Each CGI item is first evaluated on the basis of each criterion that is expressed linguistically and, later, ranked in degrees of global satisfaction. Finally, CGI items are filtered by being subject to the constraints of the application domain.

Example: Bordogna et al. (2014) employed this method to assess the quality of a CGI item (i.e. a picture) in a glaciological citizen science project.

Historical data analysis

Description: In special cases, CGI comes with historical data. In OSM, for instance, a new version of an object is created whenever its geometry is changed. From the history of the data, it is possible to derive (intrinsic) indicators that allow approximate statements to be made regarding data quality (Barron et al., 2014). An example of an indicator is the number of contributors since it has been demonstrated that this has an influence on the quality (Haklay et al., 2010). Moreover, the historical data can be analyzed to identify patterns and make predictions.

Example: Keßler & de Groot (2013) produced a set of indicators based on historical data (i.e., number of versions, contributors, confirmations, tag corrections and rollbacks) to assess the quality of OSM data in Muenster, Germany.

DISCUSSION AND CONCLUSION

CGI is obtained by means of collaborative mapping, participatory sensing and social media activities. Quality assessment is an important stage after gathering it since the information comes from unknown sources and is of unknown quality. This paper presents the results of an SLR that was carried out to discover the methods that can be employed to assess the quality of CGI in the absence of authoritative data. The search was carried out in five electronic databases to maximize the number of studies candidate to answer our RQ. After a close analysis, we found 13 methods to assess CGI quality when authoritative data is not available.

Unlike in existing studies (Section 3), we describe how each method works and what its limitations are. The limitations should be underlined because they could prevent the applicability of the method. We also classified the methods with regard to the type of collaborative activity. By doing this, we aim to highlight where each method has already been employed and, in a certain way, draw attention to areas where the method has not been applied yet.

While most of the methods have been used to assess the quality of CGI from Participatory Sensing, fewer methods were designed to assess the quality of CGI from Social Media. This can be explained by the fact that assessing the quality of this type of CGI is still a challenge due to the variety of ways the individuals communicate. However, Social Media has become a valuable source of information in the past few years since people use it share opinions and knowledge with a contact network. Thus, future studies should focus on other potential methods to assess the quality of CGI from Social Media.

Our analysis also revealed that some methods are not entirely independent of authoritative data, i.e. part of CGI dataset must have the corresponding authoritative data. One possible explanation is the lack of evidence that proves the efficiency of intrinsic analysis. Other methods rely on CGI's metadata. However, these methods could be affected because of missing metadata or privacy issues.

Although SLR is a rigorous and systematic methodology, there are some threats to its validity. These have been avoided by selecting several synonyms for both the main keywords with the aim of discovering all the primary studies in the area. However, we had to exclude some of them because we were hampered in our attempt to find relevant studies by faults/failures in the different search engines employed by each electronic database. In addition, the number of studies included might have been affected by language restrictions, as only studies written in English and Portuguese were taken into account. Thus, it is possible that some relevant studies were not included in this work.

ACKNOWLEDGMENTS

The authors would like to express thanks for the financial support provided by CAPES. Lívia Castro Degrossi is grateful for the financial support from CNPq (Grant no. 201626/2015-2) and CAPES (Grant No. 88887.091744/2014-01). João Porto de Albuquerque acknowledges financial support from CAPES (Grant no. 88887.091744/2014-01), and Heidelberg University (Excellence Initiative II/Action 7). Roberto dos Santos Rocha is grateful for the financial support from European Community's Seventh Framework Programme: Marie Curie Actions/Initial Training Networks (Grant no. 317382) and Federal University of Bahia.

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Language Limitations in Rumor Research? Comparing French and English Tweets Sent During the 2015 Paris Attacks

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ABSTRACT

The ubiquity of social media facilitates widespread participation in crises. As individuals converge online to understand a developing situation, rumors can emerge. Little is currently known about how online rumoring behavior varies by language. Exploring a rumor from the 2015 Paris Attacks, we investigate Twitter rumoring behaviors across two languages: French, the primary language of the affected population; and English, the dominant language of Internet communication. We utilize mixed methods to qualitatively code and quantitatively analyze rumoring behaviors across French and English language tweets. Most interestingly, temporal engagement in the rumor varies across languages, but proportions of tweets affirming and denying a rumor are very similar. Analyzing tweet deletions and retweet counts, we find slight (but not significant) differences between languages. This work offers insight into potential limitations of previous research of online rumoring, which often focused exclusively on English language content, and demonstrates the importance of considering language in future work.

Keywords

social media, rumoring, language, crisis informatics, information diffusion.

INTRODUCTION

The convergence of people and information at physical sites of crisis is an established phenomenon (Kaufman et al. 1958; Kendra and Wachtendorf 2003; Palen et al. 2009). Although this activity was once limited to those geographically proximal to the event, the ubiquity of social media means that participation in a crisis is now widespread (Hughes et al. 2008). Individuals and organizations from both inside and outside the physically affected area can converge on social media and participate in *collective sensemaking*—the process whereby people attempt to fill information gaps and understand a developing situation (Starbird et al. 2016), a consequence of which can be the emergence of rumors (Shibutani 1966; Starbird et al. 2016)— the circulation of unverified information (Bordia and Difonzo 2004).

Prior work has explored various aspects of online rumoring during crises, particularly on Twitter (e.g. Huang et al. 2015; Maddock et al. 2015; Spiro et al. 2012; Starbird et al. 2015, 2016; Zeng et al. 2016). The majority of this prior research however, focuses on Twitter communications in English—which only constitute around 50% of all tweets (Hong et al. 2011; Poblete et al. 2011). Less understood is how online rumoring behavior on

Twitter may vary by language, and the challenges associated with conducting online rumor research across languages. This is despite the Twitter network being structured by language (Hale 2014), with the majority of a country's Twitter content written in its own dominant language (Mocanu et al. 2013). As social media platforms are now established communication channels during crisis events (Starbird et al. 2015), the intersection of language and online rumoring behavior certainly warrants further attention.

This study focuses on tweets posted during and immediately after the November 2015 Paris Attacks. We explore rumoring behaviors across two languages: French (FR), the primary language of the affected population; and English (EN), the dominant language of Internet communication. Broadly, we seek to understand *how individuals' rumoring behavior on Twitter varies according to their proximity to an emerging crisis event.* In particular, we are curious whether proximity to a crisis, for which language serves as an imperfect but useful proxy, intersects with individuals' rumoring behavior. Considering the FR tweets as *proximal* to the crisis, and the EN tweets representing the broader audience, we specifically analyze four aspects of Twitter rumoring behavior across the languages: 1) tweet deletion and account protection since the event; 2) rumor spreading (affirmation) and correction (denial); 3) temporal engagement in the rumor, and; 4) retweeting of the rumor.

We adopt a mixed methods approach to qualitatively code and quantitatively analyze a false rumor that the *Les Halles* shopping center in central Paris was also the site of a shooting during the November 2015 Paris Attacks. Our study reveals that FR tweets are more likely than EN tweets to have been removed from public view—i.e. deleted or protected—since the event. We note similarities in rumoring and correction behaviors, but differences in the temporal engagement across languages. Although we discover variation in retweeting of rumor tweets, we do not find the differences in our sample statistically significant.

This study is a work in progress insofar as it represents an initial exploration into online rumoring across languages during a crisis event. The findings presented here are drawn from a specific rumor—the *Les Halles* rumor that emerged during the Paris attacks. This rumor provided a distinctive opportunity to investigate rumoring across languages because the name of a specific location, *Les Halles*, was used in both French and English—a convenience not often present in studies of emergent events on social media. Our study makes two main contributions. First, our analyses provide insight into the potential shortcomings (or not) of prior research into online rumoring, which are often limited to English language without considering how rumoring behaviors may vary across languages. Second, we initiate discourse into research that spans language divides, and raise the issue of considering language in studies of social media.

RELATED WORK

Language Use on Twitter

Several studies have examined language use on Twitter. A large-scale analysis of the linguistic geography of Twitter discovered that most content produced within a country was written in its dominant language (Mocanu et al. 2013). (Hale 2014) also found Twitter relationships to be structured by language, with users more likely to retweet content written in the same language as their own. In a cross-language study of Twitter usage, (Hong et al. 2011) found that 51% of tweets were English, and more than 100 languages were used. Among the ten most-used languages, differences in the use of Twitter features (e.g. hashtags, retweets, URLs, mentions, replies) were apparent. A similar study of Twitter usage by country revealed differences in the use of language itself and Twitter features (Poblete et al. 2011). Each of these studies is concerned with general Twitter usage, not Twitter usage during crisis events.

In the crisis context, (Thomson et al. 2012) conducted cross-language comparisons of online anonymity and information source credibility on Twitter in the wake of the 2011 Fukishima nuclear crisis in Japan. In this study, individuals identified as proximal to the event demonstrated an increased tendency to share information from credible sources, suggesting that during crises, physical proximity plays a role in information sharing behaviors on Twitter.

Social Media Use and Online Rumoring During Crisis Events

Crisis researchers have identified several roles of social media platforms in the crisis context: for social convergence (Hughes et al. 2008), for information sharing (Palen and Liu 2007), for situational awareness (Vieweg et al. 2010), and for self-organizing digital volunteers (Starbird and Palen 2011). Examining the Twitter retweet function, (Starbird and Palen 2010) found it was used as an informal recommendation system during mass emergencies, with individuals identified as geographically local to the event more likely to retweet local event-related information. The role of proximity was also explored in (Huang et al. 2015). This qualitative study of individuals who sought information on social media during the Boston Marathon Bombing found that information seeking and sharing behavior is likely influenced by emotional and physical proximity to the crisis.

Research into online rumoring during crisis events, particularly on Twitter, has led to the identification of multidimensional signatures to characterize types of rumors (Maddock et al. 2015); models to interpret rumor transmission rates (Zeng et al. 2016); efforts to understand the effect of situated proximity on the spread of rumors (Huang et al. 2015); and the role of expressed uncertainty in collective sensemaking (Starbird et al. 2016). In these studies, the influence that language may or may not have on rumoring is not explored, therefore the applicability of the findings to other languages remains unclear.

THE NOVEMBER 2015 PARIS ATTACKS: EVENT BACKGROUND (ALL TIMES IN CET)

On Friday November 13 2015, a series of coordinated terrorist attacks occurred in Paris, France. Nine men attacked six locations across the city, including the *Stade de France* and the *Bataclan* Theatre. Beginning at 21:20, the attackers detonated suicide explosions and fired upon crowds of people at popular restaurants and nightspots. An assault to free the hostages ended the attacks at 00:23 on November 14 2015. During the attacks, 130 people were killed and 368 injured, making it the deadliest attack on France since the Second World War. The dispersed nature of the event meant the situation was extremely confusing, with attacks and response efforts simultaneously occurring at multiple sites across the city. As events across the city unfolded, a rumor emerged of a shooting at the *Les Halles* shopping center in central Paris. The rumor later turned out to be false, and was attributed to the police response to attacks in adjacent districts. Twitter activity surrounding the *Les Halles* rumor is the focus of this study.

DATA

Data were collected using the Twitter Streaming API. Three separate collections were initiated to pick up Twitter correspondence (tweets) during the Paris Attacks. The collections went online at 21:39, 22:33, and 22:47 CET on November 13 2015. We used search terms that would collect EN and FR tweets, including: *paris, paris shooting, paris hostages, paris theatre, parisattacks, paris attack, ParisFusillades, Les Halles, shopping centre*, and *PorteOuverte*. As the event unfolded, tweet volumes were high, leading to data collection being rate limited at ~50 tweets per second per collection.

For the subsequent analysis we selected all original tweets—non-retweets—that contained the regular expression term "*halles*" and that Twitter identified as English or French. We limited our sample to tweets posted after 22:45 CET, a point in time when our Twitter collections and the tweet volumes had stabilized, and before 08:00 CET on November 16 2015, when the volume and frequency of tweets relevant to the *Les Halles* rumor in our corpus was very low. The final dataset contains 264 EN tweets sent by 227 distinct users, and 593 FR tweets sent by 551 distinct users. To place this in the context of our collections, during the same time period we collected almost 3 million original tweets related to the Paris attacks in general, of which approximately 1.8 million are EN and approximately 0.4 million are FR.

METHODS AND FINDINGS

We employed mixed methods to qualitatively code and quantitatively analyze the *Les Halles* rumor. Our analysis focused on cross-language comparison along four dimensions: 1) tweet deletion and account protection; 2) rumor spreading and correction; 3) temporal engagement in the *Les Halles* rumor; and 4) retweeting of rumor tweets. We present the methods and findings of each of these dimensions in the following sub-sections.

Tweet Deletion and Account Protection Across Languages

Investigation of tweet deletion and account protection behavior originated from a legal and ethical responsibility to remove tweets that had been deleted or protected (made private) by their author (Maddock n.d.). On July 7, 2016 we determined the current availability of our *Les* Halles tweets by passing the tweetIDs to the Twitter API. If tweets were still available (i.e. not deleted, suspended, or protected), we would receive the tweet and its associated metadata in response. If a tweet was unavailable, the Twitter API returned one of the following error codes: `144 No status found with that ID`—meaning the user has since deleted the tweet; `63 User has been suspended`—meaning the account that authored the tweet has since been suspended; and `179 Sorry, you are not authorized to see this status`—implying the tweet's author has since protected their account and tweet(s). An important distinction between the mechanism of tweet deletion and tweet protection is that individual tweets can be deleted but not protected—protection is done at the account level and therefore when a person protects their account, all their tweets are protected.

Upon completion of this process, 415 FR and 199 EN tweets were still available (i.e. public), and subject to further analysis. Table 1 summarizes the findings related to tweet deletion and account protection. 30% of FR tweets and 24.6% of EN tweets containing "*halles*" are unavailable. A greater proportion of FR tweets were deleted by the user: 17.4% FR compared to 13.3% EN. The largest difference across languages is tweet protection; 3.71% of FR tweets, but just 0.75% of EN tweets, originate from accounts that were public during the event but have since been protected i.e. made private.

Lan	Available	Unavailable		
		Deleted	Protected	Suspended
EN	199 (184) 75.38%	35 (29) 13.26%	2 (2) 0.75%	28 (15) 10.61%
FR	415 (401) 69.98%	103 (98) 17.37%	22 (18) 3.71%	53 (42) 8.94%

Table 1. Breakdown of tweet availability status. The numbers in parentheses (xx) denote the number of distinct users responsible for the tweets.

We used Chi-squared tests of independence to explore the association between language and deletion/protection behavior. Though FR tweets were more likely to have been deleted than EN tweets, the difference was not statistically significant (X^2 (1, N = 752) = 2.61, p=0.11). However, the difference for protected tweets was statistically significant (X^2 (1, N = 638) = 6.20, p=0.01), indicating that FR tweets were more likely to have originated from an account that has changed to protected since the event. This shows that those using the primary language of the affected population to engage in the *Les Halles* rumor were more likely to have protected their account since the Paris Attacks.

Rumoring and Corrections Across Languages

Comparison of rumoring behavior across languages first required translation of the French tweets into English so that they could be qualitatively coded. We recruited native French translators from the freelance marketplace UpWork (http://www.upwork.com). From the 36 responses from our job posting on the site, we selected three translators based upon their translation experience, client satisfaction rating, and familiarity with social media communications. Two translators were asked to independently translate the 415 available FR tweets and explain acronyms, slang, and subtleties in the language. Two authors of this paper verified cross-translator agreement. In 66 cases the tweet translations did not convey the same meaning, and the third translator was asked to independently translate those tweets. Selected translations were based upon a simple majority, whereby two of three translators were in agreement.

To code the rumor we adopted a similar coding scheme and process to (Andrews et al. 2016; Starbird et al. 2015), focusing on the distinction between passing along vs. correcting a rumor. Two coders previously trained to classify rumor tweets independently coded the available EN and FR tweets using a mutually exclusive coding scheme of five categories: *Affirm*—the tweet affirms or supports the [*Les Halles*] rumor; *Deny*—the tweet denies or corrects all or part of the rumor; *Neutral*—the tweet does not affirm or deny the rumor (used sparingly); *Unrelated*—part or all of the tweet is unrelated to the rumor; *Uncodable*—part or all of the tweet is unintelligible. Tweets lacking between-coder agreement were discussed until a consensus was reached.

	AFFIRM & DENY		AFFIRM			DENY		
Lan	Rumor tweets	Distinct users (tweet/user)	No. of tweets (% of rumor)	Distinct users (tweet/user)	RT mean (sum)	No. of tweets (% of rumor)	Distinct users (tweet/user)	RT mean (sum)
EN	137	134 (1.02)	124 (90.51%)	122 (1.02)	6.08 (754)	13 (9.49%)	12 (1.08)	27.46 (357)
FR	279	270 (1.03)	253 (90.68%)	247 (1.02)	22.37 (5659)	26 (9.32%)	26 (1.00)	10.12 (263)

Table 2. Breakdown of Les Halles rumor tweets illustrating rumoring, correction, and retweeting behavior across languages.

Table 2 summarizes the findings and illustrates the similarities in rumoring behavior across languages. 68.8% of available EN and 67.2% of available FR tweets that contained the term "*halles*" are rumor-related tweets that affirm or deny the *Les Halles* rumor. Furthermore, the percentage of affirmations and denials for each language are very similar: 90.5% of EN and 90.7% of FR rumor tweets affirm the rumor; and 9.5% of EN and 9.3% of FR rumor tweets deny the rumor. There is no statistically significant difference between the languages in terms of the proportion of affirmations to denials (X^2 (1, N = 416) = 0.003, p=0.95).

Temporal Signatures of Rumor Engagement Across Languages

We visualized engagement in the *Les Halles* rumor across languages through the temporal signature—the volume of tweets per 10-minute interval (Figure 1). This time series shows EN tweets reaching a higher initial peak than FR tweets (~30 tweets per 10 minutes for EN tweets vs. ~20 tweets per 10 minutes for FR tweets). However, the FR signature demonstrates a more sustained engagement in the rumor, with a sharp resurgence several hours later, and continuing at a few tweets per ten-minute interval for several hours after the initial peak. Interestingly, the shapes of the signatures are quite different in places—i.e. spikes in volume in the two languages do not always align, suggesting somewhat divergent conversations.

A notable spike in FR engagement is apparent around 18:00 CET on November 15. We traced this activity to the release of a firecracker at a memorial event held for the victims of the Paris Attacks, which took place close to the Les Halles shopping center. French tweets describe a *movement de foule*—a stampede—as people attempted to flee from what they feared was another attack. This sub-rumor was very localized; there were 24 FR tweets posted during a 1-hour period, but just 2 EN tweets during that time.

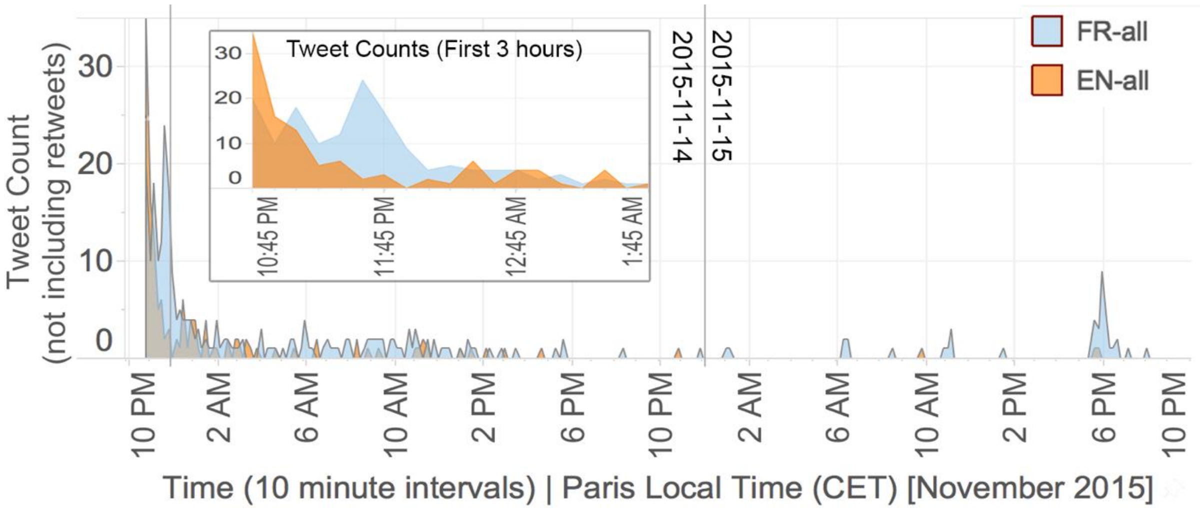

Figure 1. Time-series of rumor engagement across languages.

Rumor Retweeting Across Languages

We obtained the retweet (RT) counts for each rumor tweet from the Twitter API on July 7, 2016, approximately 8 months after the Paris Attacks. The sum and mean RT values were calculated for each of the EN and FR rumor tweets (Table 2). On average, FR affirm tweets were retweeted 22.4 times, whereas EN affirm tweets were retweeted 6.1 times, on average. Conversely, EN denials were retweeted more than FR denials. On average, EN deny tweets were retweeted 27.5 times, compared to 10.1 times for FR deny tweets. Like many measures of social media activity however, our RT data are highly skewed and zero-inflated. Although the raw counts suggest a tendency for the data, T-tests to compare the log-transformed RT counts of EN and FR affirm tweets and EN and FR deny tweets did not identify statistically significant differences.

Data Limitations

Collecting Twitter data during developing crisis event is inherently challenging. Our collections for this event are imperfect: Due to the emergent nature we missed the onset of the rumor, and high Twitter volumes led to rate limiting. Comparing RT counts in our collection to RT counts reported by Twitter, we note our collection was more comprehensive for FR tweets, likely due to rate limits across the three collections, capturing 44.90% of FR RTs and 29.68% of EN RTs. We also note that aside from language other differences likely exist among the Twitter users, although in this study we did not access users' profile information.

DISCUSSION AND CONCLUSION

The *Les Halles* rumor at the center of this study presented a rare opportunity to investigate rumoring across languages because the topic at the center of the rumor is also a specific location—the *Les Halles* shopping center— which was used in both French and English tweets. Collecting data related to crisis-related rumors is challenging, and encountering rumors with characteristics such as the *Les Halles* rumor provided a practically infrequent opportunity to explore rumoring in this context across languages.

Many studies of social media phenomena, particularly in the crisis context, focus on a single language—e.g. the primary language of the affected population, or that of the researchers conducting the analysis. In this study, we were able to span the language divide and attempt to tease out some of the potential limitations of this approach. We explore how language, which may function as an imperfect proxy for proximity, intersects with tweet deletion and protection; rumoring and correction; temporal engagement; and retweeting behavior of a specific rumor on Twitter, during a major crisis event of global interest. Our analyses consider these aspects of Twitter rumoring behavior from two perspectives: people using the primary language of the affected population (French); and people using the dominant language of the Internet and the wider audience (English). Although the data we examined were similar across several dimensions (e.g. proportion of affirming vs. denying tweets), we identified a few dimensions where there did appear to be a difference between languages (e.g. temporal engagement, account protection), underscoring the importance of considering language in future studies of social media.

Most important, as it sheds light on the validity of previous research on rumor corrections (Huang et al. 2015; Maddock et al. 2015; Starbird et al. 2015; Zeng et al. 2016), we find no significant difference in the proportion of rumor affirmations versus rumor denials across the languages. However, the temporal signatures of rumor engagement reveal slightly different patterns: English tweets appear earlier in this rumor but their volume quickly declines whereas the French ‘local’ conversation is more sustained. This suggests that those using the language of the affected population—who are perhaps more proximal to the event—were more involved in the online collective sensemaking process over time, and responsible for more of the original content, contributing eye-witness observations and knowledge to the conversation (Starbird et al. 2010). We also noticed a resurgence in the *Les Halles* rumor tweets on November 15, which was specific to the local language of the affected population—French—but did not appear in English—i.e. this related rumor did not propagate in English, our proxy for the wider audience. This may suggest some fatigue from the wider audience (Bica et al. 2017) not directly impacted by the event, while those proximal to the event were still very much affected and sensitive to developments.

Our findings also suggest differences between tweet deletion and account protection behavior. French tweets are more likely to have been deleted (though this difference was not statistically significant), and more likely to have originated from accounts that had been changed to protected after the event. Prior work in the crisis context found that deleting tweets is a method of self-correcting misinformation posted or shared [5]. The difference in deletion rate could therefore indicate self-correction was more prevalent among those using the language of the affected population. For protected accounts, one explanation for the higher numbers in FR is that local people who had protected accounts prior to the event changed their status (temporarily) to public during the event, which enabled them to participate in collective sensemaking and communicate with a broader audience. From our work we do not know *when* exactly tweets were deleted or account protected, but this opens up an interesting avenue for future research: Analyzing tweet deletions/account protections over time and across languages in the days, weeks, and months after a crisis event. Such a study would provide further insight into the role of language and proximity on self-correction and related behavior.

Although we believe that meaningful differences between languages regarding how rumor tweets are retweeted exist, we were unable to detect a statistically significant difference with the data used in this study. Future work is needed to further explore differences in the retweeting of tweets affirming and denying a rumor across languages. This exploration will require more data—possibly from several crisis events during which a rumor or rumors with characteristics similar to the *Les* Halles rumor emerge. In addition to analyzing retweet counts at a specific point in time, as we did here, exploring the retweet counts of affirm/deny tweets over time will provide a much richer picture of the spread of misinformation during emerging events.

This study provides an initial exploration into online rumoring across languages, focusing on a specific rumor that emerged during the November 2015 Paris Attacks. Our findings offer a preliminary indication that some aspects of rumoring behavior (e.g. corrections) do not vary substantially by language, but that other aspects (e.g. temporal engagement, tweet deletion/account protection) do differ in meaningful ways. Certainly, language is an aspect that requires further consideration when conducting studies of social media.

ACKNOWLEDGEMENTS

This research is a collaboration between the emCOMP lab and DataLab at the University of Washington and was supported by NSF Grants 1420255, 1541688, 1640940, and PAC121028. We also wish to thank the UW SoMe Lab and Conrad Nied for providing infrastructure support, as well as the many students who provided significant assistance to this project.

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Towards a Crowdsourcing-based Approach to enhance Decision Making in Collaborative Crisis Management

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ABSTRACT

Managing crises is considered as one of the most complicated organizational and managerial task. Indeed, dealing with such situations calls for many groups from different institutions and organizations to interact and collaborate their efforts in a timely manner to reduce their effects. However, response organizations are challenged by several problems. The urgent need of a shared and mutual situational awareness, information and knowledge about the situation are distributed across time and space and owned by both organizations and people. Additionally, decisions and actions have to be achieved promptly, under stress and time pressure. The contribution outlined in this paper is suggesting a crowdsourcing-based approach for decision making in collaborative crisis management based on the literature requirements. The objective of the approach is to support situational awareness and enhance the decision making process by involving citizens in providing opinions and evaluations of potential response actions.

Keywords

Crisis management, decision making, crowdsourcing, SBPMN.

INTRODUCTION

Nowadays, great technological, economical and socio political changes shape our world. This dynamic and complex environment brings the entire society to a range of challenges and exposes it to a complicated climate leading to crisis and disaster situations. A variety of response groups from different organizations need to collaborate and coordinate their efforts in order to contain and handle such events. A process by which, crisis management organizations need to obtain and share a mutual on-the-ground picture of the situation, gather and access critical real-time information, and share response action plans and resources for purpose of making fast and efficient decisions. However, recent crisis events have led respondent organizations to revise their protocols so as to expand the range of contributing actors, by including simple citizens as well as expert operators, to support decision making activities (Ginige et al., 2014). Furthermore, recent studies on crisis and disaster situations have shown that citizens' involvement and participation can lead to better results in term of crisis response. Alongside with the emergence of the web 2.0, scholars and practitioners have made a lot of attention to the concept of "Crowdsourcing", and studies are increasingly converging on this paradigm (Vivacqua and Borges, 2010). Crowdsourcing is considered as a valuable mean used to leverage the community's knowledge and skills, and is seen as a collaboration model enabled by people-centric web technologies to solve individual, organizational, and societal problems using a dynamically formed crowd of interested people who respond to an open call for participation (Pedersen et al., 2013). Moreover, (Brabham, 2008) claims that crowdsourcing is considered as a model capable of aggregating talent, leveraging ingenuity while reducing the costs and time formerly needed to solve problems and make decisions.

In fact, crisis management is about making decisions in a timely fashion under stress and time constraint, with lives and properties at stake. Thus, it depends on efficient sharing and exchange of updated information, and having a shared and mutual situational awareness by the involving stakeholders. Usually, making a decision involves the three phases of the well-known decisional model of Simon: intelligence (information gathering and sharing for problem identification and recognition), design (generating alternative courses of action), and choice (evaluating, prioritizing, and selecting the best course of action). In particular, acting in a collaborative situation may requires negotiations and dynamic exchange of suggestions and alternatives between decision participants, which is to a certain extent a time-consuming process. Furthermore, from one hand, Simon's theory of decision making is based on the idea that decision makers did not have a complete knowledge about the situation. On the other hand, developing a crisis management strategy will depend on its unique features. Thus, additional sources of information, knowledge and skills are required to perform better and efficient decisions. Crowdsourcing in this regard, is highlighted as a very relevant mean to cope with these challenges. From the same perspective, (Bonabeau, 2009) highlights the limitations of individual decision makers in solving business problems and raises the question of what if we rely more on others to find those solutions. Moreover, Bonabeau underlines the power of recent advances in technologies and their capacity to harness the collective intelligence on greater scale than ever before. He claims that crowdsourcing, wisdom of the crowds' concepts, social networks, collaborative software, and other web-based tools constitute a shift paradigm in the way that organizations make decision and calls this emerging era: Decision 2.0.

In this work, we try to examine how crowdsourcing can influence the different phases of the decision making process in a collaborative crisis management situation. To this end, the paper is structured as follow: after discussing the literature revue, we present and discuss the crowdsourcing-based approach for decision making that relies on Crowds participation for each phase of the process. Thereafter, we use the Social Business Process Model to highlight the collaboration work that exists between both the response organizations and the citizens within a collaborative crisis management situation.

BACKGROUND

Collaborative Crisis Management

Collaboration is a dominant characteristic of every crisis management initiative. Indeed, it is widely outlined by the literature that, crisis response management is a collaborative activity which requires a highly cooperation between response organizations to face and recover from the unwanted outcomes of crisis and disasters events. Several cases such as September 11, terrorist attacks and Hurricane Katrina disasters have proven that traditional emergency management tools and methods characterized by centralization and hierarchy-based policies need to be revised (Kapucu and Garayev, 2011). In this trend, The Geographic Information and ICT communities are increasingly involved in the definition and design of methods and techniques that guarantee a better management of the coordination work based on a unique, and shared collaborative platform, which allows collecting information through several sources, query, manage, and analyze this collection in a seamless manner (Ginige et al., 2014).

Due to its complex and dynamic nature, coping with crises requires joint efforts from many collaborating organizations in response to the event (illustrated in figure 1), and presents many challenges in order to make it successful. Indeed, it is quite evident that decision making efficiency, accurate awareness of the situation, and taking advantage of the collective intelligence are very dependent upon the good communication and collaboration between crisis response organizations or teams. By reviewing the literature, we can distinguish three main approaches of communication and information systems for crisis management:

- Emergency Response Information Systems;
- Decision Support Systems;
- and Web 2.0 and Social Networking based solutions.

Especially in large-scale crisis situations, the tendency is remarkably oriented towards web-based systems (Volunteered Geographic information systems, Spatial Decision Support Systems, Crowdsourcing systems) regarding the dispersed nature of respondent teams and the possibility of large public involvement.

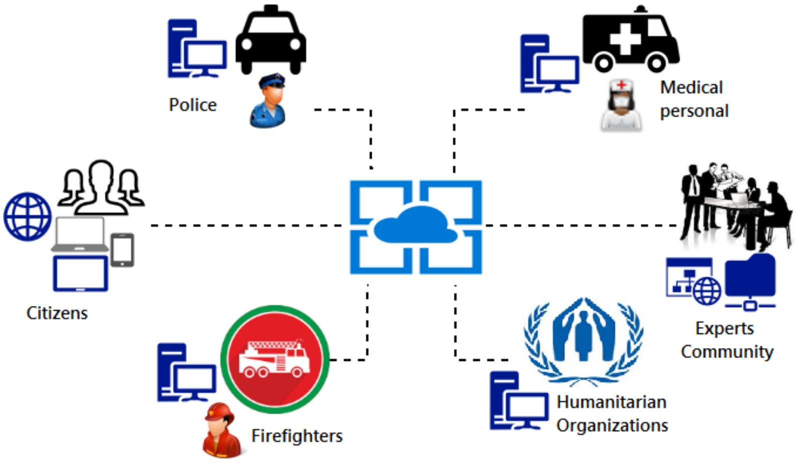

Figure 1: Example of collaborating stakeholders in collaborative crisis management

Decision Support for Crisis Management

The decision making process during crisis and disaster management has been covered in the literature and studies have highlighted its complexity (Diniz et al., 2005; Ley et al., 2014). In such collaborative and dynamic situations, different collaborators interact with each other and joint their efforts in order to have cooperate and effective actions and making collective decisions. Moreover, it is no longer accepted that decisions are made statically by few centrally located individuals. Regarding its changing nature, a crisis situation entails delegation of decision making to those experts best suited to have authority to make decisions (Turoff et al., 2008). Turoff et al claim that "Deferring to Expertise" is something too often lacking in crisis events. They suggest that having a fully dispersed command and control center, and delegating authority based upon the expertise of the participants for the current requirements, will promote continuous ability to function effectively in face of such events. Moreover, (Othman et al., 2014) stated that crisis management involves collaborative decision making activities often characterized by a high level of complexity involving different sources of knowledge distributed across time, space and people. The knowledge used to make decisions in time of crisis is available in different forms, and can be of different nature (Diniz et al., 2005) as depicted in figure 2.

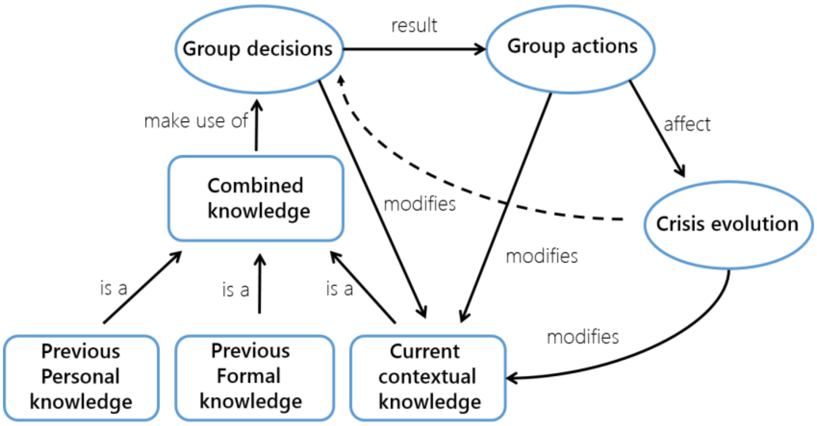

Figure 2: Conceptual map of knowledge support during crisis management (Diniz et al., 2005)

The "*previous personal knowledge*" is embedded in each crisis responder's mind. The second form consists of any information or knowledge relevant to the decision coming from a reliable source other than the individual's own mind (local maps, water sources, etc.). This knowledge is usually explicit, does not change during the course of the crisis evolution, and is called "*previous formal knowledge*". The third type is called "*current contextual knowledge*", which is generated by the crisis itself or by the response to it. We can distinguish two types of current context: one corresponds to the crisis phase (mitigation, preparedness, response, and recovery), and the other including the actions performed by the crisis response teams.

(Holsaple, 2008) presents a pyramid drawing the relation between the different knowledge states and the decision making process of Simon. The decision making process is considered as encompassing a complete set of knowledge states: data, information, structured information, insight, judgment, and decision. Various operations can be undertaken to progress from one state to another. For instance, by selecting from data, a processor obtains the next higher knowledge state (i.e., information). From selecting, other operations include analyzing, synthesizing, weighing, and evaluating.

In spite of the collaborative nature of crisis management activities, few studies have treated the aspect of collaborative decision making (Yu and Cai, 2009; Kapucu and Garayev, 2011). This is may be related to the fact that crisis situations require rapid decisions. On the contrary, the negotiations and the dynamic exchange of suggestions and alternatives between decision makers to a certain extent is a time-consuming process and involve mutual situational awareness of the crisis context. To cope with these issues, Geographic Information Systems and Online mapping technologies represent key elements for participatory decision making. In fact, using map-based online discussion can increase both organizations and community awareness, and offer a flexible participatory decision making processes (Kapucu and Garayev, 2011). Furthermore, Geospatial Annotation Systems can provide an effective communication and analysis platform to enrich the dialogues among various stakeholders in spatial decision making processes, which explicitly links participants' discussion contributions with their geographic references in the map (Yu and Cai, 2009).

As can be seen, geographic information systems and online mapping technologies have been considered as powerful tools used to overcome collaborative decision making biases. These challenges will increase proportionally with the number of involved stakeholders having different cultures and protocols. Large public and volunteer communities gain more involvement in the process and additional efforts may be required to find better integration and configurations of these new displayed parameters of the decision making process.

Crowdsourcing-based Crisis Management

Several crisis and disaster situations such as Haiti earthquake and Japan Tsunami, have shown that crisis affected communities tend to share and update situated information. This geographic information have been of vital relevance for the involved organizations to allocate resources, prepare plans, and prioritize actions for response and relief. However, given its diverse format and large amount, response organizations unfortunately, have a limited staff, resources, and ability to acquire, synthesize and evaluate this geographic information. With the emergence of the web 2.0 and the high advances in information and communication technologies, citizen's participation to the crisis management process have shifted from just providing data and information without processing it (social media tweets, etc.) to more active participation by performing specific tasks (interpret, evaluate, and aggregate geographic information) as illustrated in figure 3. This emerging process is known as "crowdsourcing phenomena".

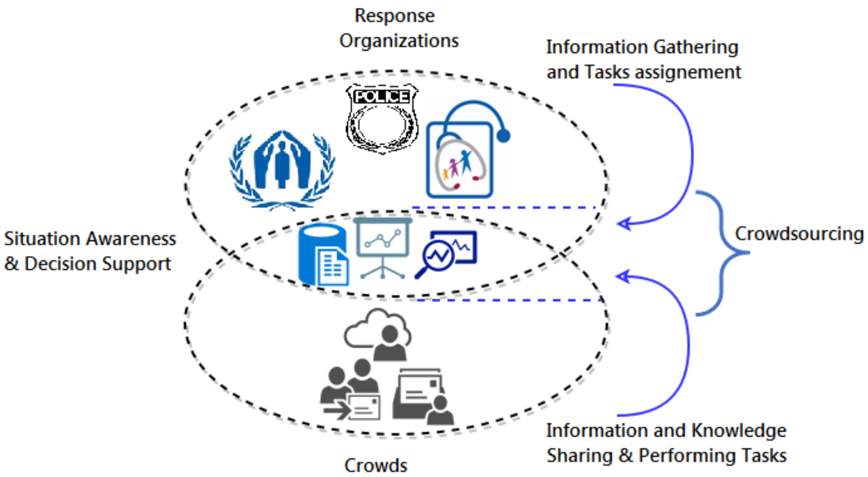

Figure 3: Crowdsourcing support process in collaborative crisis management

Crowdsourcing is considered as a multi-disciplinary domain and many initiatives exist in the literature to clarify such an umbrella term. (Estellés-Arolas and González-Ladrón-De-Guevara, 2012) based on available definitions have tried to synthesize them and give a more exhaustive and consistent one. "*Crowdsourcing is a type of participative online activity in which an individual, organization, or company with enough means proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task. The undertaking of the task, of variable complexity and modularity, and in which the crowd should participate bringing their work, money, knowledge and/or experience, always entails mutual benefit*".

Beside its great benefits, crowdsourcing implementation presents a panoply of outstanding issues. The trustworthiness and accuracy of the crowdsourced information are the most challenging issues to be considered. Indeed, engaging crowds in performing tasks might require particular knowledge and skills. Therefore, the crowds as a hole have to be "Wise" to some extent. In this regard, (Surowiecki, 2005) calls this particular characteristic "the Wisdom of Crowds". Moreover, Surowiecki proposes four conditions for crowds to be wise:

- Cognitive diversity, by which involved individuals have different backgrounds, Knowledge, and skills;
- Independence, wherein each contributor's participation is independent from each other's;
- Decentralization, through which people are allowed to make their own independent decisions;
- Aggregation, which represents a mechanism for transforming many contributions (opinions or decisions) into a collective one.

Crowdsourcing is a very ambitious area of research, which has attracted a lot of attention from crisis informatics scholars and practitioners during the last decade. So, many initiatives have been conducted by researchers to address different considerations and challenges to be taking into account while implementing the latter, and to extract the best configurations of crowdsourcing for efficient mobilization of volunteers, knowledge/or skills, and available resources in crisis situations. (Liu et al., 2014) based on several vignettes, propose a Framework serving as systematic, problem-driven approach to determine the why, who, what, when, where, and how aspects of a crowdsourcing system. The framework also draws attention to the social, technological, organizational, and policy (STOP) interfaces that need to be designed to manage the articulation work involved with reducing the complexity of coordinating across these key dimensions. (Schimak et al., 2015) present an overview of the crowdsourcing applicability for crisis and disaster management. Thereafter they present several examples of crowdsourcing and crowdtasking at work, discuss key characteristics and challenges of crowdsourcing in crisis management and finally outline a generic methodology and functional architecture for future crisis management crowdtasking tools. Similar to this work, (Poblet et al., 2014) present an overview of technological (online platforms and mobile apps) solutions that are currently applied in the area of emergency management and have in common the use of data generated and/or processed by large numbers of citizens via social media and social networks. The authors distinguish different roles of the crowd based on the type of data being processed and the level of participation involved. Then, they discuss the applicability and association of roles in each phases of the crisis management cycle.

PROPOSED APPROACH

Crisis events put the response community in a unique environment that requires critical real-time distributed decision making. Making fast and efficient decisions needs an accurate situational awareness picture of the event, and depends on the effective use and coordination of resources, people, and information, where information and knowledge are distributed and owned by both organizations and citizens.

Based on the work done by (Holsaple, 2008) and the framework proposed by (Liu, 2014) presented in the background point 2 and 3, we examine the applicably of the crowdsourcing sub processes to the decision making process in the crisis management context. We delineate the "who, why and how to do it" of Liu's Framework for each phase of Simon's decisional model (as shown in figure 4). We include citizens into the decisional process, either by providing information about the crisis or as volunteers performing specific tasks related to information management needs. The crowdsourcing-based approach should enable the participation of both citizens and crisis response organizations, assisting the decision making process of the latter. In this approach, crisis actors can act both as consumers and as providers of information, so information will circulate in a two-way mode. On one hand, citizens provide real-time information about the event in order to exhibit an accurate situational awareness and a shared on the ground picture for the involved response organizations. On the other hand, organizations share their plans and resources to both citizens and the others crisis management organizations to obtain a clear activity awareness of the crisis management community.

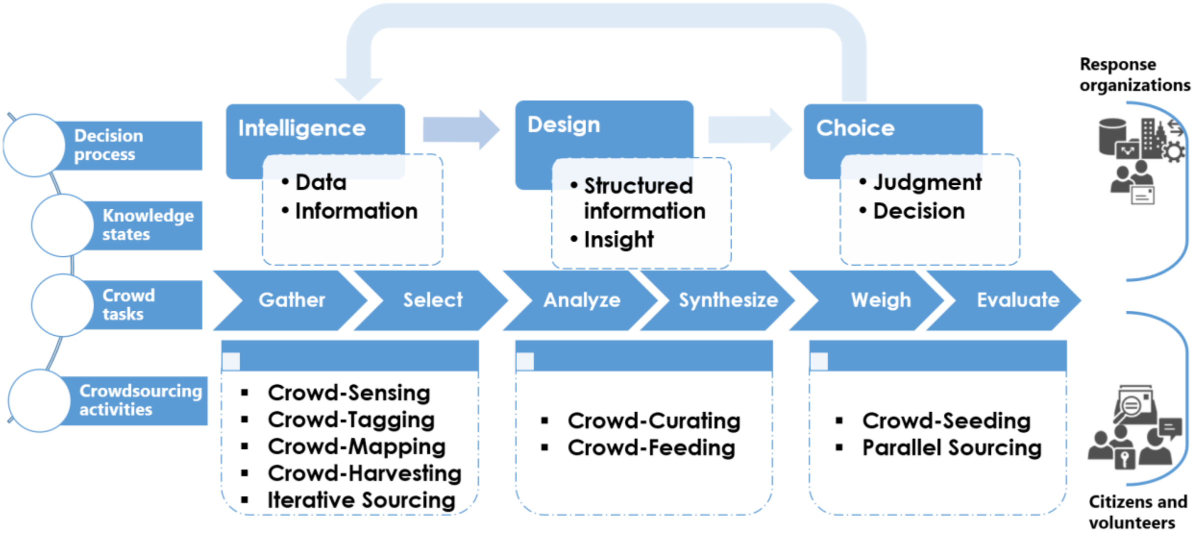

Figure 4: Crowdsourcing-based decision making approach for crisis management

The Intelligence phase

In this phase, response community seeks for a clear and accurate situational awareness about the affected region, which volunteers can offer through empirical eyewitness reports. Affected populations and Diasporas are relevant actors in this phase. They are directly and immediately involved in gathering data and information related to the crisis place and its impacts. Moreover, they proceed to information selection and sharing based on their local knowledge of their own environment. In other words, citizens tend to gather, select and share information about what they sensed and observed in the crisis field, and this process in known as "Crowd-Sensing". A process that have been made very easy and extremely fast due to the widespread use of Social networking technologies and mobile devices. However, the collection process may produce a large amount of unstructured data and information, which generates information overload problems. Consequently, crowds have to be involved in categorization and classification of the provided data through "Crowd-Tagging process". In this regard, situational awareness ontologies may be of potential use in order to overcome confusions of terms regarding the differences in protocols and systems between the different stakeholders. First responders need a general idea or picture about the impacted area, that is, crowds are asked to Geo-locate and Geo-tag (marking features on a map) the crisis or disaster zones using mapping tools (Google earth, Open Street Map, etc). This process may require skilled persons using professional tools like ArcGIS or ordinary participants using tools such as the OSM. The crowdsourcers iteratively improve the work done by previous workers, which facilitate a sequential improvement of the data quality by allowing ongoing participations of different crowds. The very basic participation of the crowd to information management process can be just providing raw data by using phones, tablets, and their social networks (GPS coordinates of the device). This one-way passive contribution is known as the "Crowd-harvesting process".

The Design phase

In this phase, we shift from simple data and information to more established and structured information. The Crowds in this case and based on the available information and their own knowledge and skills, proceed to information processing and management for giving insights and proposing possible alternatives in terms of actions. Both Social networks and digital volunteer communities are required for this purpose. In fact, the existing trust between the socially connected crowds affects how one interprets the quality and the reliability of the solutions produced by the crowds. Moreover, social networks tend to bring together a variety of backgrounds and expertise relevant to the crisis. At this stage of the decision process, the ultimate objective of the crowd is to find actionable crisis information and then share it in a meaningful way to key stakeholders, which may require filtering, analyzing, synthesizing, and then exhibiting a curated version of the information to the crisis management stakeholders. For instance, first situational reports provide real-time information used to measure affected population needs, existing resources, shelters, and infrastructure ability. The main objective of the Crowds is to reduce irrelevance and redundancy of information in these documents, analyze demands based on victims' locations and health conditions, types of supplies, etc. A synthesized report is then sent to the response organizations in order to prioritize the rescue operations, and elaborate a coordinated plan for supplies distribution. Thereafter, the presented information and insights are processed and then shared back to the crowd for more adjustment. This active two-way feedback loop represents the "Crowd-Feeding process".

The Choice phase

This phase concerns the evaluation of the proposed solutions and courses of action proposed in the previous stage. Evaluation can be made through voting mechanisms to select the most appropriate alternatives. This form of crowdsourcing involves an active one-way request and only selected members of the crowd can participate to this process. For instance, both diasporas and digital volunteers' community are called for this assessment process to avoid social interference that can be engendered by affected population and social networks. To this end, the parallel sourcing is the most relevant model where participants evaluate the same alternative independently of other's choices. The parallel approach is based on decentralization, which reduces consequently the likelihood of each participant to be influenced narrowly by the work of previous crowds.

In fact, information needs differ for each phases of the crisis management cycle, for different response organizations, and vary for each stage of the decision making process. Moreover, information and knowledge are geographically distributed, with a high degree of diversity and heterogeneity. Additionally, decision makers did not have the ability to locate and process the needed information required for specific tasks by different crisis response teams. In this regard, information filtering, indexing, categorizing, and linking are extremely important to exhibit through an enormous volume of dynamically collected information those that are most relevant to each specific crisis response task. As a result, facing these challenges is certainly going to make a great deal of information management issues. In light of these challenges, crowdsourcing comes as a powerful tool leveraging the collective intelligence of the crowd and the available resources through the intermediary of a dedicated crowdsourcing platform.

To exhibit the coordination work that exists between the response organizations and the involved citizens in the decision making process, as illustrated in fig 5, we use the Social extension of Business Process Model (SBPMN) that aims to define a specific notation for describing Social BPM behaviors (Brambilla et al., 2012). The main objectives of the SBPMN is making the internal decision procedures more visible to the affected stakeholders, assigning an activity to a broader set of contributors, and eliciting opinions that contribute to the decision making process.

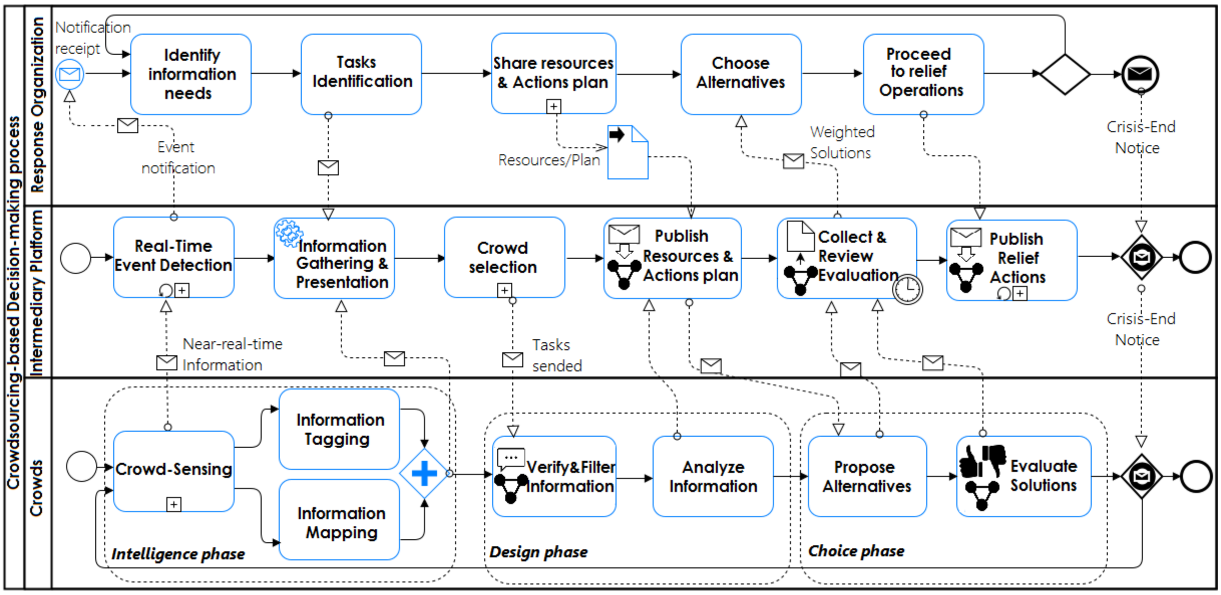

Figure 5: SBPMN model for the Crowdsourcing-based decision making in crisis situations

The crowdsourcing Platform should make use of knowledge discovery algorithms to automatically detect Near-real-time information through their simple use of social media and social networks to report eyewitnesses of the event. In addition to using citizens as human sensors, the Platform may incorporate existing devices sensor networks to the information gathering process. After identifying information needs, crisis management organizations carry out tasks assignment process, which may be performed based on citizens' profiles (crowd selection) using data mining and machine-learning techniques. For instance, Diasporas and affected population are more needed in the information tagging and mapping sub processes. After receiving Synthesized and aggregated information from the crowd, response organizations can share their resources and plans of relief actions for both citizens and the other organizations. In order to get a real-time distributed planning and coordination of response actions, avoid multiple responses to the same request at the same time, and reuse available resources by different organizations in different times. Crisis responders can also share or publish potential alternatives for citizens to have feedbacks and evaluations of these alternatives. The generation of first plan of actions has to be realized by either internal or external experts to ensure a reliable start. It can be supported by case based reasoning systems, which allow retrieving of past crisis situations based on features similarities, and provide solutions for the new event. Presentation of the collected information, resources, plan of actions and relief operations can be done using visualization and collaborative technologies such as online mapping tools or Geo-collaborative tools. It will enhance the situational awareness picture, guide the efficient coordination and co-creation of courses of action, and facilitate the participatory decision process.

RELATED WORK

Crisis management stakeholders need effective plans and procedures in place to prepare for, respond to, recover from and mitigate the potential effects of crisis events. A corner stone of these plans is knowing what needs to be known and providing this knowledge to the right person in the right place and at the right time. Unfortunately, not all situational knowledge is immediately available, not all knowledge is coming from the same place, and not one person will be qualified to make all decisions (Othman et al., 2014). Furthermore, over and over again it has been seen that in unexpected problems, decision authority flows down to those closest to the situation in either location or knowledge (Turoff et al., 2008).

One of the first initiatives that have studied the crowdsourcing application for decision making is the work done by (Bonabeau, 2009). In his model, Bonabeau suggests that crowdsourcing based decision making process is composed of two phases: the generation of potential solutions and their evaluation. Thereafter, he tackles the decision making process issues that must be taking into account when calling for crowd's participation. In the generation phase, issues such as social interference (participants tend to follow others ideas and opinions), availability (participants tend to be satisfied with the easy solution), anchoring (generated alternatives are focused on the first one), and stimulation (been influenced by how a solution is presented) are addressed. To handle these issues, he proposes for organizations to consider three general types of approach: outreach, additive aggregation, and self-organization. In the alternatives evaluation phase, the set of alternatives is reduced to a smaller one, which can then be evaluated. This process invokes either the integrity of the crowd or a small part of experts. One way or another, (Rosen, 2011) suggests that Bonabeau's discussed issues are well managed when aligned with Surowiecki's conditions of diversity, independence, and decentralization (Surowiecki, 2005). Furthermore, Rosen claims that the two previous works lack consideration of other factors such as compensation for participants, crowdsourcing quality, and communication with crowdsourcing partners. He suggests that an ongoing dialogue, a give and take, between the crowd and the organizations will certainly improve the quality of the ideas generated. Thus, organizations must balance communicating information to the crowd against maintaining their secrets. Closer to this work, (Chiu et al., 2014) propose a Framework to outline the role of crowdsourcing in each phase of Simon's decision making model:

- *Intelligence phase*: like highlighted previously this step consists of information gathering and sharing for problem identification, so crowdsourcers can be involved in search and discovery activities as well as knowledge discovery and accumulation, giving opinions, and making predictions.
- *Design phase*: in this phase, organizations call for crowd's participation in ideas and alternatives generation, which can be performed by different ways: Soliciting ideas from employees (in house mode) or from customers or other outsiders. Two forms of idea generation are addressed: collaborative which is recommended when dealing with knowledge accumulation activities, and competitive generally used to find solutions to a problem or to improve performance.
- *Choice phase*: Crowds are called for analyzing and evaluating generated alternatives and ideas, they can vote on the proposed solutions and give feedbacks as well.

Chiu et al, then identify potential areas of interest for future research, which include finding a balance between diversity and homogeneity in the crowd, definition of relationships between the crowd and the organizations, tasks assignment to participants, reduction of groupthink and other decision biases in the crowdsourcing process.

(Hosio et al., 2016) examine the possibility of using crowdsourcing or the wisdom of crowd to offer on-the-fly decision support. The presented framework is centered on two aspects of decision support systems: populating the knowledge base and exploiting the populated knowledge base. Participants can contribute to the knowledge base construction by rating options in term of criteria. In the decision support stage, users can manipulate the importance of each proposed criterion using simple sliders, and recommendations are presented to the end-users based on the adjusted criterion and the used decision model.

As can be noticed, Crowdsourcing represents a very powerful mean that have been leveraged to assist decision making activities. Yet it presents many challenging issues in order to make it successful. Surowiecki's conditions have been considered as a general framework for reflection on these issues in the aforementioned works. A compromise between these conditions is necessary to enhance the decision making efficiency, which will depend on the specific characteristics of each situation.

To the best of our knowledge, available literature addresses the applicability of crowdsourcing in decision making for general and arbitrary problem domains and lacks research that examines in particular the crisis management area.

CONCLUSION

In time of crises, response organizations operate in a new and unique situation. A situation that requires rapid and optimized information gathering, providing contextual knowledge to right person at the right time in the right place, and making time-critical decisions that translates into crisis relief operations. In such situations, a huge amount of data and information are generated with different types, distributed and owned by both organizations and the affected community. From this variety and large volume of data and information, decision makers need to obtain the most relevant and accurate information, extract actionable information, having better insights about the situations in order to make the right judgments. Such a process necessitates large efforts, a variety of backgrounds and skills under stress and time constraints, which may exceed capabilities of the involved organizations and calls for the contribution of the directly affected population to the response process.

Our contribution outlined in this paper is suggesting a crowdsourcing based approach for active citizens' participation to the different phases of the decision making process to face the multitude of information management challenges. The approach will help response organizations to identify the information needs, be aware of the crisis situation evolution, and provide decision-makers with useful recommendations based on affected volunteers' community propositions and evaluations.

Given its collaborative nature, the idea behind crowdsourcing platforms is to allow a more established collaboration between different involved organizations and the large public. However, in reality, the platforms lack collaboration between the response organizations in term of planning and coordination of relief actions. In this regard, crowdsourcing applications must allow the possibility of integration of collaborative tools into the Crowdsourcing systems to overcome coordination barriers.

In our future work, we intend to propose a crowdsourcing-based architecture system of decision support system for collaborative crisis management situations. This architecture will be founded on: literature requirements of collaborative tools and decision support systems design, Crowdsourcing best configuration and conceptualization, and empirical studies. The point is to examine real scenarios of crisis situations in order to get a practical view point of the challenging issues, and barriers faced by the response community, and to determine and analyze the communication and decision making biases in the course of crisis response actions.

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Temporal Sampling Implications for Crowd Sourced Population Estimations from Social Media

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ABSTRACT

Understanding the movements of a population throughout the 24-hour day is critical when directing disaster response in an urban area. An emergency situation can develop rapidly, and understanding the expected locations of groups of people is required for the success of first responders.

Recent advances in modern consumer technologies have facilitated the generation, sharing and mining of an extensive amount of volunteered geographic information. Users leverage inexpensive smart devices, pervasive Internet connections and social media services to provide data about geospatial locations. Using an enterprise system, it is possible to aggregate this freely available, geospatially enabled data and create a population estimation with high spatiotemporal resolution, via a heat map.

This investigation explores the effects of different temporal sampling periods when creating such estimations. Time periods are selected, estimations are generated for several large urban areas in the western United States, and comparisons of the results are shown/discussed.

Keywords

Population estimation, emergency response, temporal sampling, volunteered geospatial information, data mining.

INTRODUCTION

In recent years, incidences of human and climate related disasters have become more prevalent. In addition to loss of life and injury; these disasters have a grave economic cost that can affect communities for many years (Yohe et al., 1996). The reasons for the increase of emergency situations are complex, and include human-driven climate change, aggravated geopolitical relationships, and utility infrastructure that has not been properly maintained (Henderson, 2004), etc.

The focus of this work is to explore the use of previously collected, volunteered geographic information (VGI) during an emergency situation. Before a disaster, this freely available data can be continuously collected from social media services, stored in an enterprise solution, and aggregated to generate an hour-by-hour estimation of population via a heat map (Wilkinson and Friendly, 2009). The data can then be viewed in a geospatial information system, which can include a dynamic map as well as other data layers; allowing an end user to select a coverage based on day-of-week and hour-of-day (Toepke, 2015). Recent research primarily focuses on the application of a full set of collected data which can inveigle emergency responders to trust a population distribution estimation that lacks precision. Instead of using a full set, a result generated from different time sampling periods may present a very different spatiotemporal estimation of a local population.

Using multiple, highly populated urban areas, this investigation shows the implications of using different time periods while generating a visual population estimation from the VGI.

BACKGROUND

Traditionally, population estimation has been affected using a combination of census data, time-use surveys, soil cover maps, satellite imagery, etc. These methods require a large investment of time, energy and cost, are slow to complete, and are of low spatiotemporal resolution. Nonetheless, novel methods are being actively investigated to leverage the traditional data, and create a higher quality result. LandScan (Bharduri et al., 2002) is a population estimation product that provides a day/night heat map at a resolution of 1km^2, and uses a fusion of the aforementioned traditional products. Combining population data with high risk geographic areas can provide insight during the planning stages of disaster response (Freire and Aubrecht, 2012).

Modern adoption of interconnected technologies has allowed the realization of the human-as-a-sensor paradigm (Laituri and Kodrich, 2008). Social media services are being investigated as to their utility in multiple stages of a disaster: alerts, preparedness, response and rebuilding (Coyle and Meier, 2009). This investigation will focus solely on the response aspect of a disaster; from the perspective of someone directing an immediate relief effort.

Novel ways VGI is being used include capturing video from live-streaming services such as Periscope (Fichet et al., 2016); which was useful during the 2015 South Carolina flooding, and was used to spread first-hand perspectives of the developing damage. Social media is also useful in generating occupancy curves for a structure (Stewart et al., 2015), which can present the spatiotemporal occupancy of a building over the span of a twenty four hour day. VGI cannot currently present an absolute population representation, but can supplement traditional methods of population measurement, or be used singularly with the understanding that the data is an estimation, and only possibly indicative of population trends.

Using VGI is not without challenges. From trustworthiness issues (Tapia et al., 2011), to the sheer deluge of available data (Sui et al., 2013), processes are necessary to ensure the quality of the data. Due to the preliminary state of this work, no cross checking, extraneous/dense post filtering and/or outlier removal is occurring; though the precision of the generated product would be increased, and this should be investigated in further work. Other concerns include under representation of smart device non-adopters, those that do not partake in social media services and/or those without the fiscal means necessary to purchase such devices. The population estimation could also be skewed by a user's propensity to geo-tag a tweet, and that social media services tend to be used more by younger individuals.

The social media service of choice for this work is Twitter; a freely available platform which allows users to post 140 character 'tweets'. The tweets can be geospatially enabled with a latitude/longitude tag, thus allowing data for a specific location to be generated. Twitter maintains a public application programming interface (API) that can be queried using standard web services.

While the combination of multiple social media services has been shown to enhance situational awareness (Panteras et al., 2015), only a single social media service is explored in this case.

Five major cities from the western United States were chosen; each with a high population, dense downtown area, and high technology use/adoption. The cities are as follows:

- Portland, Oregon; the largest city in Oregon.
- San Diego, California; a sprawling port city with several institutions of higher learning, high tech industry and multiple military installations.
- San Francisco, California; a highly populated urban space in the Bay Area.
- San Jose, California; one of the largest cities in California, and inside the Silicon Valley.
- Seattle, Washington; founding city of many technology firms.

Further reasons for picking these specific cities can be found in (Toepke, 2017).

ARCHITECTURE

Geospatially enabled, crowd-sourced Twitter data is gathered using an enterprise solution based on elastic cloud and web services. Amazon Web Services (Services, A. W., 2015) and Java Platform, Enterprise Edition (Java Platform, Enterprise Edition, n.d.) are the primary technologies used to implement this investigation. The data is queried from an Internet connected web service; any compatible programming language and/or cloud services suite would suffice.

The AWS technologies used are as follows, and are visualized in Figure 1:

- Lambda, runs as a scheduled task twice an hour and executes the source code, using a serverless, code-in-the-cloud paradigm.

- DynamoDB, is leveraged as a fully managed, NoSQL object store for the Twitter data.
- Elastic MapReduce (EMR), Data Pipeline, and S3 export the Twitter data to a text file for local processing.
- Identity and Access Management, CloudWatch and CodeCommit are used for security, computational resource management/observation and source code revision control, respectively.

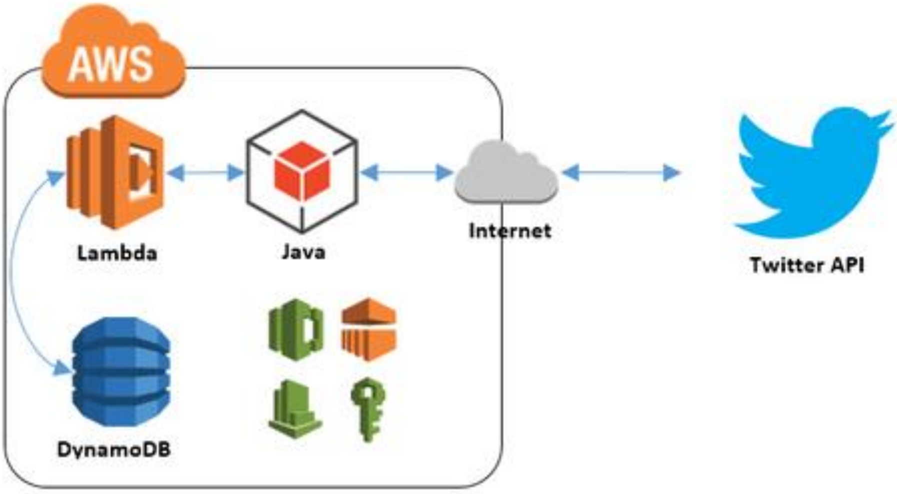

Figure 1. AWS Twitter Query/Storage Architecture

Once a volume of data has been obtained, custom Java code was written to run the experiments, based on different time sampling lengths. A snapshot of the data was created from DynamoDB, and exported for local processing. Results are visualized using GNU Octave (GNU Octave, n.d.), and are discussed in the Results/Observations section.

The Google Maps Javascript library, and a standard web browser are also used to visualize and display generated heat maps. Google Maps is chosen arbitrarily, though Google Earth, World Wind, OpenLayers, etc. would also be useful in displaying this data.

The different sampling lengths are as follows:

- Full length. The entire set of data, from beginning to when the data export occurred. In this case, approximately five months of collected data. The population estimation from the full set is used as a control when comparing with the other results.
- Most recent last four weeks. Corresponds to about a month's worth of data. Each weekday will have approximately four days to generate an average estimation.
- Most recent last eight weeks.
- Most recent last twelve weeks. Corresponding to about three months, will account for seasonal changes in population patterns.

Heat maps of several urban areas are also generated and visually compared using Google Maps, to easily view the implications of data used from different time boundaries.

An in-depth discussion of the architecture can be found in (Toepke, 2017), as both investigations rely on the same infrastructure.

RESULTS/OBSERVATIONS

The data consists of geospatially enabled posts from the Twitter API occurring from 2016-06-07 23:01:35 (GMT) to 2016-11-04 23:57:03 (GMT). A publicly available web service API was used to download the data in a JavaScript Object Notation format. The data period is an arbitrary artifact of the time between when the collection services were fully activated, and when an end-point was required for analysis. The collection code is currently still running, and replication of these experiments with data from a longer period may be of interest for follow-on work.

Over the collection period, a total of 447,386 unique Tweets were collected from the five cities. The specific breakdown for each city can be seen in Table 1 and Figure 2.

Table 1. Total Tweet Count Per City

City	Tweet Count
San Jose, CA.	49,557
San Francisco, CA.	62,555
Portland, OR.	85,745
San Diego, CA.	115,574
Seattle, WA.	133,955

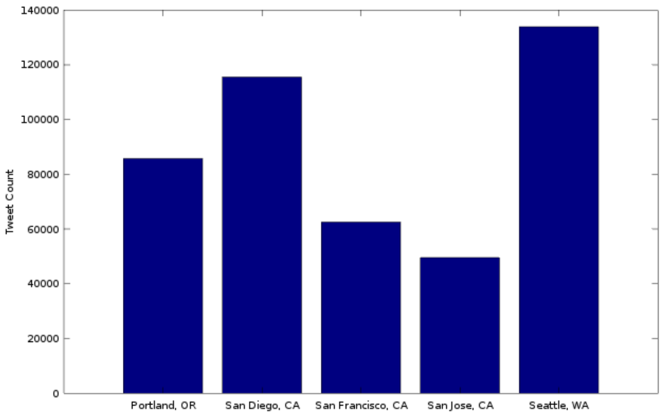

Figure 2. Total Tweet Count per City, 2016-06-07 to 2016-11-04

Using Saturday as an arbitrary day of interest, Figure 3 shows average Tweets per hour over the course of the day. The data is normalized using an algorithm which sets the vector length of each dataset to 1 (Abdi and Williams, 2010); eliminating the visual differences in Tweet quantity for each city.

The data shows expected patterns; of low posting throughout the night-time hours, with a sharp increase corresponding to day-time hours. San Francisco, CA. and Portland, OR. show a slow start to the day, while San Diego, CA. and San Francisco, CA. continue posting for longer towards the end of the day. An almost vertical drop in post quantity can be seen in between 1700 and 1800, when the typical workday ends. On average, the most activity occurs between the hours of 1100 and 1700.

An algorithm was then developed to remove data points based on the time lengths described in the Architecture section, with results shown in Figure 4. The algorithm was run several times, each time taking the last timestamp of collection, and removing Tweets that were older than four weeks, older than eight weeks, and older than 12 weeks. This was implemented using standard Java temporal data types, and Unix epoch time representations.

Visual inspection shows a similar pattern to the full results in regards to posting throughout the day. As to the different time periods, the following observations can be made.

- The data from the past 4 weeks in comparison with the full data shows: higher posting between 0900 and 1100, and lower posting between 1800 and 0500.
- In 9 of the 24 observed hours, 8 weeks and 12 weeks track each other closely, while being between the values for 4 weeks and the full data set.

While the data is indicative that there is a different population trend in these estimations, at least in the past 4 weeks as compared to the full data set, it is difficult to extrapolate the reason. More compelling to the use case of an emergency responder directing resources would be an immediately understandable visual comparison. Using Google Maps, two example cases and their results are shown in the following subsections.

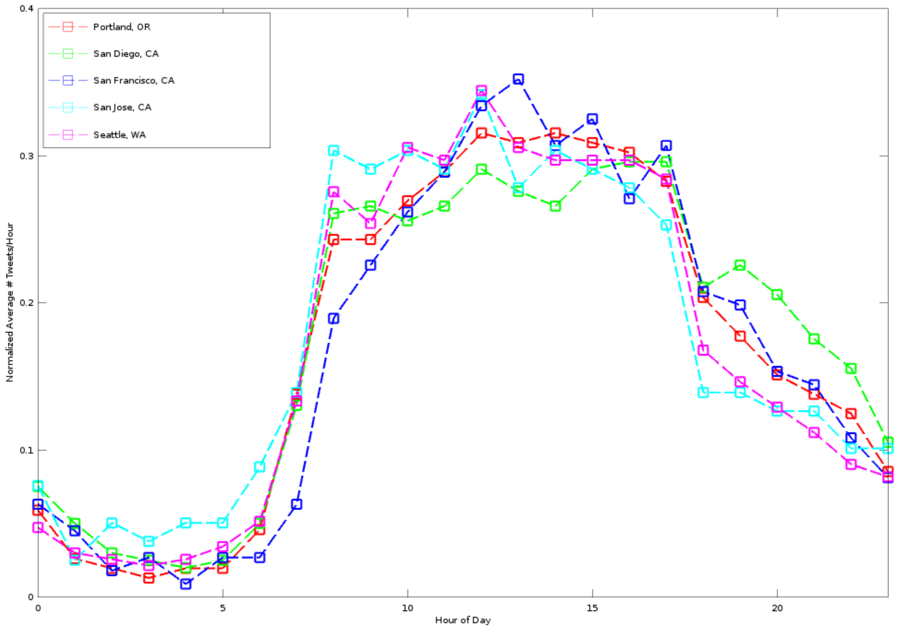

Figure 3. Normalized Average Tweet Count per Hour on Saturdays, 2016-06-07 to 2016-11-04

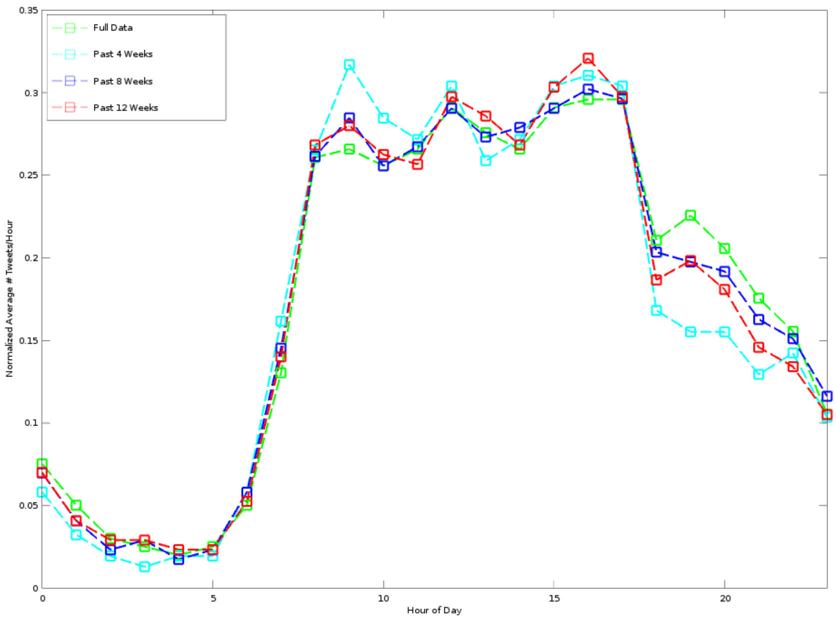

Figure 4. Normalized Average Tweet Count per Hour on Saturdays with Different Time Sampling Periods for San Diego, CA., 2016-06-07 to 2016-11-04

San Diego, CA. Saturday at 1700, Full Data vs. The Last Four Weeks

Figure 5 shows a heat map comparison of the full data set vs. the most recent four weeks. Of note, the four week heat map shows a lack of Tweets at the San Diego Convention Center and Petco Park. While event scheduling at the Convention Center is more dynamic, Petco Park is a baseball stadium that hosts sporting events based on a fixed schedule. The Major League Baseball regular season for the year ended October 2, 2016 (2016 Major League Baseball Season, n.d.); since the most recent four weeks look back starting at November 4, 2016, the lack of Tweets in this area is as expected.

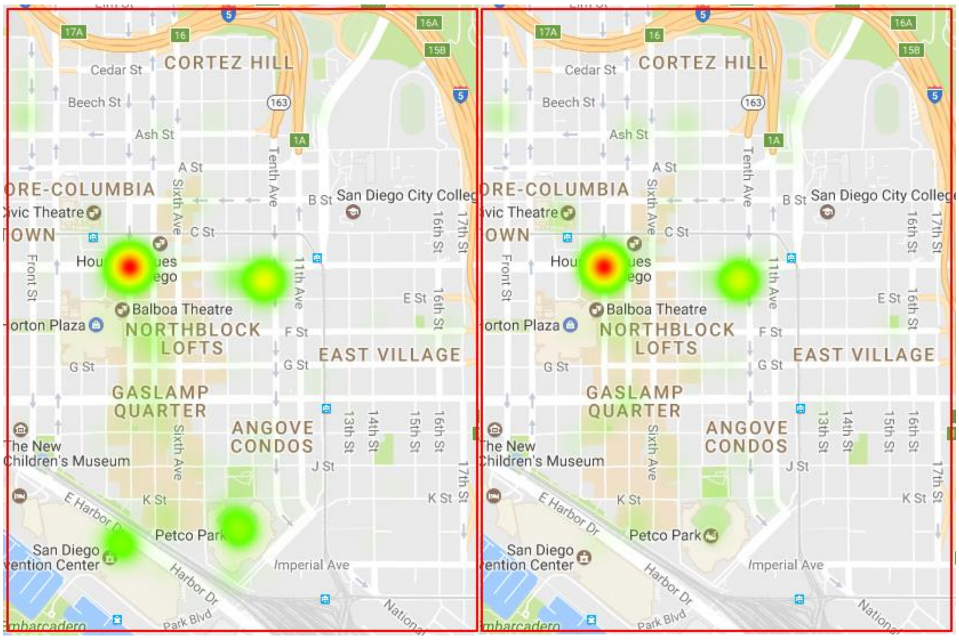

Figure 5. San Diego, CA., Saturday at 1700, Full Data (L) vs. Previous Four Weeks (R)

San Jose, CA. Saturday at 1700, July 2016 vs. October 2016

Figure 6 shows a heat map comparison of the data from the month of July 2016 vs. October 2016. While not directly useful for immediate response, comparison of two different months of the year can show the importance of the temporal window. Information of this type can be used for long term emergency response planning.

With the limited volume of Tweets, it is difficult to visualize the heat map differences at this resolution. Nonetheless, July shows a more vibrant downtown 'scene', with hotspots at street corners populated by taverns and restaurants. October shows less activity in those areas, but with a concentrated spot over San Jose State University, which is in session at this time. The subtle change in population dynamics would be understood by local first responders at the city/county level; but federal and/or state responders would not necessarily have that domain knowledge. The areas of interest are bordered with an orange quadrangle.

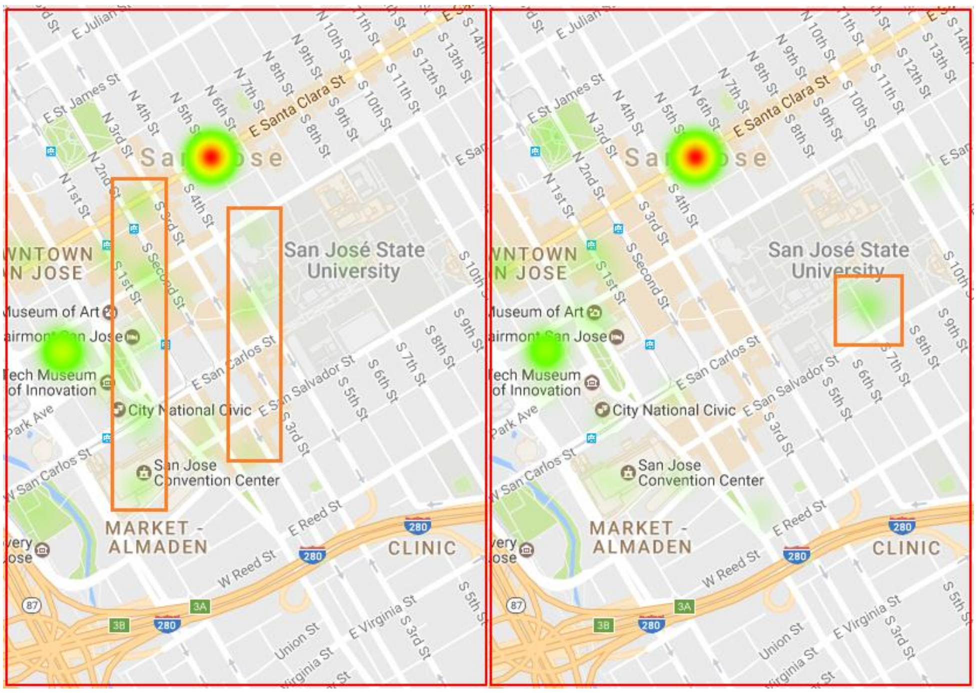

Figure 6. San Jose, CA. Saturday at 1700, July 2016 (L) vs. October 2016 (R)

FOLLOW-ON WORK

This is a preliminary study, and many avenues of investigation exist for follow-on work:

- Verification of data against objective measure. E.g. turnstile data from transit stations, or person-tracking data from a location constrained environment. A heavily trafficked corporate campus that implements electronic security measures would be a good source for this comparative data.
- A longer data collection period, further comparisons investigating different seasons of the year, and their effect on population patterns. This is especially relevant for cities that are affected by weather patterns like Seattle, WA. and Portland, OR. On the other hand, San Jose, CA. and San Diego, CA. tend to have more consistent weather throughout the year.
- A broader data set, gleaned from multiple social media services e.g. Facebook, Foursquare, Panaramio, etc. Performing the same experiments with data from different services can help generate a more precise population estimation.
- Investigation of hybrid-representations of temporal sampling utilizing weighting. E.g. a downtown area may have a different winter-time use pattern, and also many popular boutiques that heavily trafficked during the end-of-year holiday season. A hybrid algorithm that is perhaps weighted 40% for the past 4 weeks to represent the effects of weather, and weighted 60% for the past two weeks to represent the commercial shopping, could provide a more complete picture.
- Enriching the dataset by pulling data from more than five cities. Also, experimenting with cities that do not have a high population, or tech adoption. The benefits/pitfalls of using social media data to create heat maps can be better explored with a more diverse set of data. Integration of traditional methods of population estimation, e.g. land use maps, time use surveys, and/or census data. The combination can make for a more robust estimation, resilient to areas that do not exhibit high levels of technology adoption. This would also include those that choose to not use social media services, or are physically/fiscally unable to do so.
- Heat map acceleration/deceleration investigation. Calculating the average rate of change of expected heatmaps for each hour and/or time period can assist in the recognition of emerging situations. An unexpectedly large change in a heat map for a certain time period and area can be indicative of an unusual situation, which can be brought to the attention of a human decider. Fusion with other social media sensing methods, e.g. real-time keyword/hashtag parsing, can provide a more informed disaster warning system.

CONCLUSION

This investigation has shown the implications of time period selection when using social media data to generate population estimations of densely populated areas. Crowd sourced data from Twitter is procured from a publicly available API, experiments are run using data from different time periods, and differences in the resulting estimations are discussed. It can be seen that different time periods have different estimations when compared to the full dataset, as a city's dynamics change in response to the use patterns of its denizens. While still a preliminary investigation, this work has shown that different sampling periods can give an end user deeper insights into the spatiotemporal population dynamics of a city for emergency response and disaster recovery.

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Social Media Analyst Responding Tool: A Visual Analytics Prototype to Identify Relevant Tweets in Emergency Events

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ABSTRACT

Public and humanitarian organizations monitor social media to extract useful information during emergencies. In this paper, we propose a new method for identifying situation awareness (SA) tweets for emergencies. We take a human centered design approach to developing a visual analytics prototype, SMA-RT ("Social Media Analyst Responding Tool"), informed by social media analysts and emergency practitioners. Our design offers insights into the main requirements of social media monitoring tools used for emergency purposes. It also highlights the role that human and technology can play together in such solutions. We embed a machine learning classifier to identify SA tweets in a visual interactive tool. Our classifier aggregates textual, social, location, and tone based features to increase precision and recall of SA tweets.

Keywords

Situation Awareness, Social Media, Emergency Management.

INTRODUCTION

When an emergency happens, social media may provide information from the public that can contribute to SA of emergency operation centers (EOCs) (Hiltz and Plotnick, 2013). For example, Twitter reported that during Hurricane Sandy in 2012, people sent more than 20 million tweets about the storm within 6 days (Marina, et al., 2015). This on-the-ground and updated information enhance an emergency response team's SA by helping them allocate resources and coordinate rescue actions (Imran, et al., 2014). In the tsunami of data from social media, only a few gems provide information that is operationally relevant. In addition, information often arrives at a high rate, making it difficult for social media analysts in EOCs to manually monitor, analyze, and filter such texts in time-critical emergencies (Hiltz, et al., 2014).

In response to these challenges, we have developed a visual analytics tool that would help identify SA tweets in emergency situations. In the academic literature, several efforts use machine learning classifiers to develop novel filters to categorize social media posts (Imran, et al., 2015) . These automated classification approaches use a quantitative evaluation in which they measure the accuracy of a classifier according to a given test dataset of emergency events. These studies demonstrate the applicability of classifiers and text mining techniques for automated social media classification (Hughes, et al., 2014). However, Applying these automated classifiers in another emergency can drop their accuracy because they may be over-fitted with the training data set (Power, et al., 2013). Therefore, analysts need filters that can learn from historical data and yet change according to analysts' needs in real-time. To facilitate such filters, we design SMA-RT in a way so that analysts would be able to train the machine learning classifier in real time.

Our approach combines human expertise as well as intelligence with machine learning methods through a set of visual analytics techniques. We develop interactive visual emergency-related filters, and use the microblog Twitter as an example of social media streams that can provide relevant information in emergencies. This research has the following contributions: (1) Develop a machine learning classifier to identify SA related tweets using textual, social, location and tone based features to increase precision and recall of SA tweets (2) Design and develop a visual analytics prototype informed by social media analysts in an iterative manner to improve task performance of analysts in the emergency situations.

RELATED WORK

In this section, we provide an overview of how data mining and visual analysis techniques have been used for identifying relevant tweet in emergency events. Some studies apply machine learning classification to identify different tweet types. *Emergency Situation Awareness (ESA)* (Yin, et al., 2012) distinguishes those tweets that are reporting an infrastructure damage using classification learning method based on NLP and social based features. Diakopoulos et al. (Diakopoulos, et al., 2012) developed a tool known as Seriously Rapid Source Review (SRSR) to enable journalists to assess sources around breaking news. The classification based studies demonstrated the applicability of learning models with text mining techniques to automate Microblog filtering (Hughes, et al., 2014). Various textual and social based features had been extracted from the social media posts to be able to classify this information into various categories. Verma et al. (Verma, et al., 2011) designed classifier models to distinguish tweets that are contributing to SA from tweets that are not. This study used text-mining and tone based features to identify tweets that represent SA. Rudra et al. (Rudra, et al., 2015) proposed a framework to extract a summary of SA information from tweets. The proposed framework combine and summarize tweets.

Another study proposed a visual classifier tool named *Scatterblogs* (Bosch, et al., 2013). Scatterblogs utilized a binary classifier based on text similarity to distinguish emergency-related tweets. This method allowed users to visually filter related tweets in real-time, and then train and update the classifier model. In Thornton et al. (Thornton, et al., 2016), the feedback-based techniques were used to improve SA instead of traditional key-word based by updating the selected features in the learning model. AIDR (Artificial Intelligence for Disaster Response) (Imran, et al., 2014) study proposed a platform to apply automatic classification on emergency-related microblog posts. Their objective was to classify microblogs into a set of user-defined categories, combining machine learning classification techniques and human participation in labeling emergency-related microblogs in real-time. In our work, we extend this approach. First, we bring insight to the design of such tools by interviewing social media analysts in the emergency domain. Next, we extract and aggregate different groups of features (social based, tone based, location based, and textual) to identify SA tweets. Finally, we embed the proposed classifier in a visual analytics tool to bring the human into the classification loop and provide feedback to the classifier.

THE DESIGN PROCESS

SMA-RT was iteratively developed using an agile process focused on social media analysts. Social media analysts are those who are monitoring and analyzing social media information. Depending on the organization, the terminology of what the role can be called might be different (e.g. digital communication officer, public information officer, or social media analyst). Regardless of naming, all those roles monitor social media information to get a sense of a situation (e.g. what public and media are saying about an event, what are the trends, rumours, etc.). Initially, we **interviewed** emergency practitioners and social media analysts in emergency domain to understand their challenges and requirements when monitoring social media (Marbouti and Maurer, 2016). One of their main requirements that we gathered from these people was that there is a need for the ability to identify posts that can contribute to their SA during an emergency event. After the initial interview phase, we pursued a **scenario based design approach** (Carroll, 2000) to consider the variety of context in which the tool might be used and shape the feature set. We focused on designing a prototype to help develop advanced filters using analyst's knowledge and machine learning algorithms. We produced **low-fidelity prototypes** and showed these to social media analysts to gather their reaction and comments. Using this feedback, we iterated on the design and implemented the core features in a fully functional prototype. Finally, we demoed the prototype to the same analysts to gather further feedback. In the remainder of this section, we describe SA classifier, then we describe how we reflected analysts' feedback in the SMA-RT development and provide an overview of the core elements of the prototype and, finally we share the initial feedback on the prototype that we gathered from social media analysts.

Situation Awareness Classifier

We developed and implemented a classifier for identifying situation awareness related tweets. Compared to conventional document classification problems (Sebastiani, 2002), tweet classification is more challenging because less information is available as input for the classification. tweets use non-standard vocabulary, abbreviations, and are short in length (Tuarob, et al., 2014). Because of the short length, they often do not provide sufficient context information. Spelling and grammar problems reduce the performance of standard automation techniques such as named entity extraction (Rogstadius, et al., 2013). In each classification problem, we need to represent our instances (i.e. tweets) as a set of features. Choosing the right features seems crucial when it comes to tweet classification and can improve the accuracy of a classifier model. We extract several features that contribute to deriving situation awareness information (see Table 3). The features are inspired by the related work (Landwehr and Carley, 2014), interviews, and manual exploration of emergency-related tweets. We group them into four categories:

(1) Textual features extract information from the message using text-mining techniques. Considering the short length of a microblog, use of abbreviations, and the ambiguity of natural language, using only these features would not be enough for determining an effective classifier (Tuarob, et al., 2014). The common text mining features are Bag of words (BoW) and TF-IDF. **(2) Tone** Based Features measure the tone of the tweet which can contribute in determine SA (Verma, et al., 2011). Assessing the emotional and social content in a tweet can help in assessing the situation on the ground. We use IBM Watson Tone Analyzer (part of the IBM Watson Developer Cloud toolchain) to extract different tone based features from the tweet text after removing the URLs. IBM Watson utilizes NLP and machine learning techniques to analyze and extract insights from vast unstructured volumes of text. In this section, we extract social and emotional tone analyzers. **Emotional tone** infers from different types of emotions and feelings that people express in their language. For each of these emotions, the Watson service generates a score between 0 and 1, which expresses the probability that the emotion came across in the text. **Social tone** measures the social tendencies in people's writing. Similar to emotional tone, the service outputs a score that lies between 0 and 1, which indicates tendency toward each social tone. **(3) Location** based features can determine the importance of a tweet in the emergency context (Schulz, et al., 2013). For example, the location of the author indicates if the author is a potential eyewitness or not. If the tweet is not geo-tagged, we investigate if the author uses any location words to describe a specific area within the emergency region. **(4) Social Media** Based features are related to Twitter specific characteristics. Along with other features they can contribute to predicting SA (Karimi, et al., 2013). Table 1 shows the detail features that we used for each feature category.

Table 1. List of features for identifying SA Related Tweets

Feature Category	Feature Name		Feature description
Textual Features	BoW + TFIDF		BoW (Aggarwal and Zhai, 2012) represents the text as a vector of words. TF-IDF (Salton and Buckley, 1988) measures Term frequency within a tweet whereas the frequency within all tweets. Each word in the bag of words feature is represented with its TF-IDF score.
Tone based Features[1]	Emotional Tone	Fear	"*A response to impending danger. It is a survival mechanism that is a reaction to some negative stimulus. It may be a mild caution or an extreme phobia.*"
		Sadness	*"Indicates a feeling of loss and disadvantage. When a person can be observed to be quiet, less energetic and withdrawn, it may be inferred that sadness exists."*
		Disgust	"*An emotional response of revulsion to something considered offensive or unpleasant. It is a sensation that refers to something revolting.*"
	Social Tone	Extraversion	*"The tendency to seek stimulation in the company of others*."
		Openness	*"The extent a person is open to experience a variety of activities."*
		Agreeableness	*"The tendency to be compassionate and cooperative towards others."*
Location Based Features	Tweet Distance		If the tweet is geo-tagged, we measure the distance of the tweet to the center of the crisis.
	User Distance		Since according to Twitter less than 1% of the tweets are geo-tagged, we also consider the registered location of the users as a measure of how close the user is to the center of the crisis. By using geographical APIs, we extract geographical coordinates for users if they have a valid place name in their profile.
	Location mentions		Since not all users have a valid and registered place in their account, we use tweet text as another source of extracting location information. We determine number of location mentions in the text.
Social Media Based Features	Number of Mentions		Tweets with important information usually mention authorities or government related accounts (Karimi, et al., 2013). In this feature, we measure the number of times an account has been mentioned in the tweet.
	Photo		Sometimes people provide photos of the scene when posting about it. In this feature, we measure whether a post contains photo or not.
	Mobile		Eyewitnesses at the scenes usually send SA posts with a mobile phone (Kumar, 2015). In this feature, we determine if a tweet has been sent using a mobile device or not.

[1]The definitions are based on Watson tone analyzer's documentation (https://www.ibm.com/watson/developercloud/doc/tone-analyzer/understanding-tone.shtml)

Location Extraction Process

One of the features in the SA classifier was determining if a tweet text contains location information or not. In this section, we describe the process in which we extract locations from a tweet text.

Box-based Location Extraction Process: In this process, we start with query for locations based on a bounding box around the incident area. Then, with these extracted locations, we check if any of them are contained within the tweets. Figure 1 demonstrates the process.

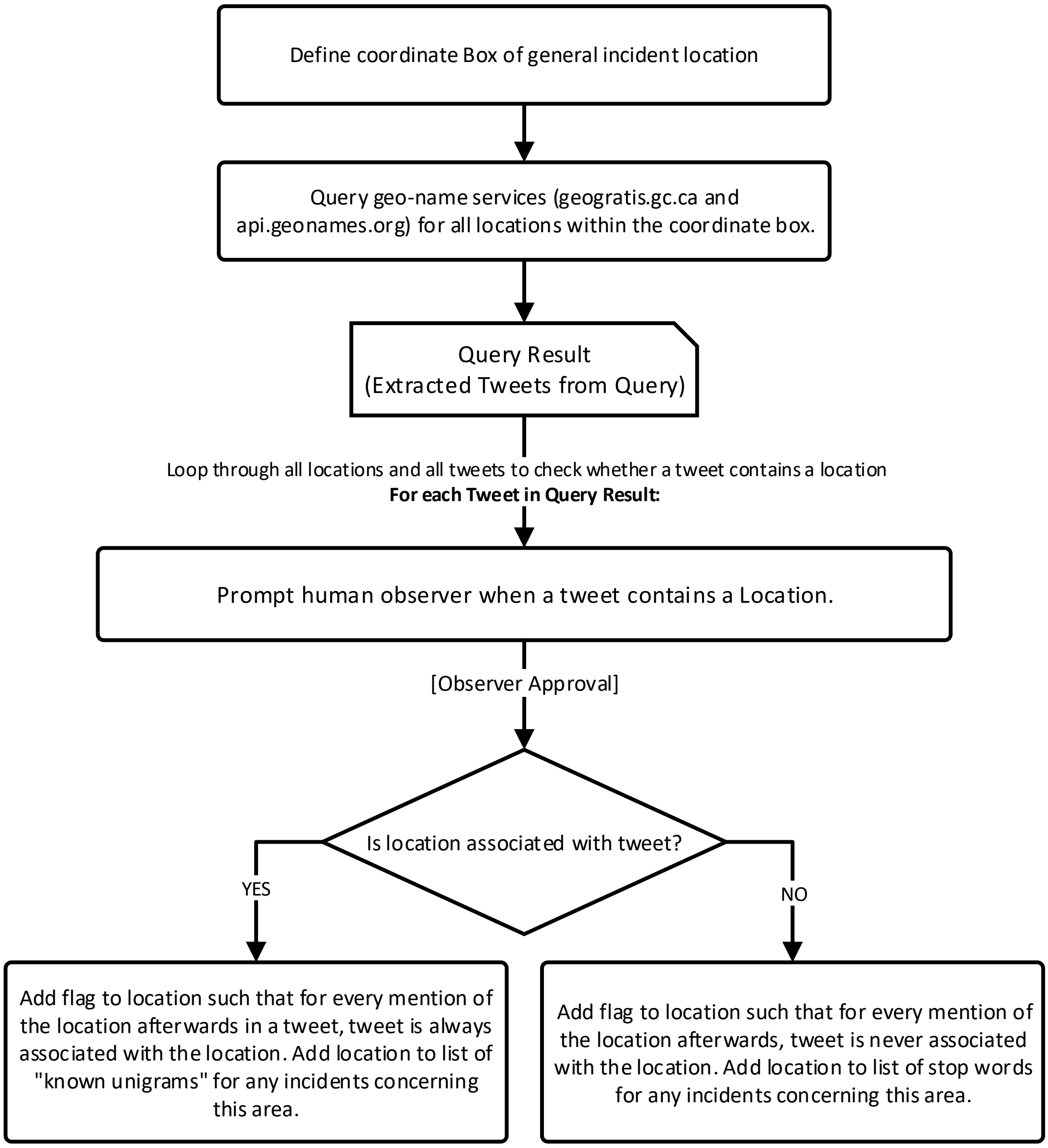

Figure 1 Box Based Location Extraction Process

Bigram Based Location Extraction Process: A second location extraction process has also been performed to support the first process in the likely cases that the first process does not cover all location mentions. This process is based on extracting bigrams for each tweet by using the NLTK python library. Figure 2 shows the process detail.

Step 1: Use stop words and "known unigrams" list from the Box-based process. Supplement "known unigrams" with additional Observer-chosen locations based upon researching the incident.

eg: "known unigrams": *{"ymm", "toronto", "fortmac", "yyc", "yea", "yed", "yec", "yeg", "highriver", "calgary", "lethbridge", "edmonton", "wetaskawi n", "ftmcmurray", "fortmacmurray", "anzac", "attawapiskat", "chipewyan", "mcmurray "}*

Step 2: Remove Links from the tweet: e.g. *"WATCH LIVE: Long says new evac centres opened up in Drayton Valley and St. Paul #ymmfire #abfire"*

Step 3: Tokenize the tweet: *"WATCH" "LIVE:" "Long" "says" "new" "evac" "centres" "opened" "up" "in" "Drayton" "Valley" "and" "St." "Paul" "#ymmfire" "#abfire"*

Step 4: Find Bigrams Tuples of each tweet: *"('WATCH', 'LIVE')","('LIVE', 'Long')", "('Long', 'says')","('says', 'new')","('new', 'evac')", "('evac', 'centres')","('centres', opened')", "('opened', 'Drayton')", ('Drayton', 'Valley')", "('Valley', 'St')", "('St', 'Paul')", "('Paul', '#ymmfire')", "('#ymmfire', '#abfire')"*

Step 5: Remove special characters, ellipses and stop words. Set all to lower cases. *"('watch', 'live')","('live', 'long')","('long',")", ('',''), ('','evac'),"('evac', 'centres')","('centres', 'opened')", "('opened', 'drayton')", "('drayton', 'valley')", "('valley', 'st')", "('st', 'paul')", "('paul', 'ymmfire')", "('ymmfire', 'abfire')"*

Step 6: Remove all empty string items: *"('watch', 'live')", "('live', 'long')","('evac', 'centres')","('centres', 'opened')", "('opened', 'drayton')", "('drayton', 'valley')", "('valley', 'st')", "('st', 'paul')", "('paul', 'ymmfire')", "('ymmfire', 'abfire')"*

Step 7: Create all possible two word combinations: *"watch live", "live watch", "live long", "long live","evac centres","centres evac","centres opened", "opened centres","opened drayton","drayton opened", "drayton valley","valley drayton", "valley st", "st valley", "st paul", "paul st", "paul ymmfire","ymmfire paul", "ymmfire abfire", "abfire ymmfire"*

Step 8: check if any of the tokens from Step 3 are in list of "known unigrams"? None are associated with the example tweet in this case.

Step 9: Query geoname service for unigram/bigram in given Country (optional state/province). If a location is found, associate location with tweet. For example, the combination of *"drayton valley"* returned Drayton Valley Location, and *"St Paul"* returned St. Paul Location.

Figure 2. Bigram Based Location Extraction Process

We evaluate the location extraction process by applying it into three emergency events datasets and randomly sampled 1% from each. To get a more uniform distribution, the dataset that we created consisted of 50% that our location extractions process identified a location in and 50% that our process did not identified a location in. Table 2 shows the evaluation results of this process. The process shows a higher performance for centralized events. The hurricane Matthew event has the lowest precision out of our samples, as this was a more distributed event with several locations.

Table 2. Location extraction accuracy results based on 1% random sampling

Emergency event	Precision	Recall	Location List
Fort McMurray Fire	0.58	0.95	Fort McMurray
Alberta Floods	0.78	0.98	Edmonton, Calgary
Matthew Hurricane	0.50	0.96	Cuba, Haiti, South Carolina(USA), North Carolina(USA), Florida(USA), Virginia(USA), Georgia(USA)

Classifier Evaluation

In this section, we report our initial results of the SA classifier performance. We use Twitter Search API to obtain publicly available tweets during emergency events. We collect tweets for FortMacmurry Fire and Hurricane Matthew events using search terms that we chose through an initial investigation of public Twitter stream. We also purchased Alberta floods event dataset. We removed all retweets and duplicates in tweet texts as these do not provide additional information. We also removed the URLs from the tweet text. We randomly sampled 3% of the tweets from this set and performed a manual coding on whether a tweet is contributing to SA or not. Tweets were coded by 3 volunteers. For example, the following tweets coded as SA as they provide actionable insights regarding an event that can be useful for both affected public or emergency responders and help them make informed decisions.

Thickwood North under voluntary evacuation with 30 minutes notice expected for mandatory evacuation #ymmfire #fortmac

UPDATED: Forest fire has shifted away from homes. #ymm #ymmfire

On the other hand, the following tweets were code as not SA. These tweets may mention the event within their text but they did not provide any actionable information for emergency responders or affected public.

That situation in Alberta don't sound too good #ymm #ymmfire
Hope everyone in #ymm is safe this evening. Wish #yyc was a bit closer so we could offer some shelter. Thinking of you all! #ymmfire

Since we have heterogeneous features we used a Support Vector Machine (SVM) classifier with a linear kernel which is known to perform well on heterogeneous features (Kotsiantis, 2007). Performance was evaluated by measuring precision, recall and F1-score. We randomly split the data 80% for training and 20% for testing. Table 3 displays the classification results. It also displays the most effective features groups for each event. We plan to compare the performance of our classifier with the benchmark datasets.

Table 3. SA Classification results for three emergency events

Event Name	Search terms	Features used	Precision	Recall	F1-Score	Numebr of labeled tweets
FortMacmurry Fire 2016	#ymmfire, #FortMacfire, #ymm, #ymmHelps	TFIDF+Tone+location	0.83	0.80	0.81	2760
Hurricane Matthew 2016	Matthew, Hurricane, HurricaneMatthew	TFIDF+Tone+ location+ Social	0.89	0.86	0.87	2673
Alberta Floods 2013	This dataset was purchased from Gnip (www.Gnip.com)	TFIDF+Tone+ location	0.90	0.85	0.87	3171

SMA-RT development

This section describes the design of the SMA-RT application, including the various features that we have developed based on interviews with analysts. Figure 3 shows the core elements of our proposed design. The SMA-RT interface combines the ability to collect, search and sort tweets alongside the functionality to filter and organize them with machine learning techniques. In the following we describe the core parts of the design in more detail.

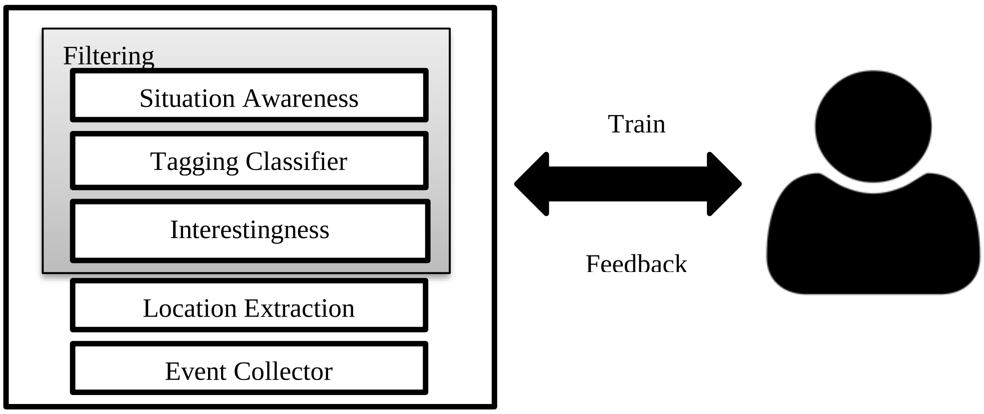

Figure 3. SMA-RT design overview

Event Collection: An essential feature of a social media monitoring tool is to be able to collect social media posts while an event is occurring. The collection component in SMA-RT partitions tweets into three types of collections: Event Collections, Filtered Event Collections and Manually Filtered Event Collections. Event Collections (Figure 4-A) contain the total tweets related to one large main event. Upon the start of using the prototype, a user must create an Event Collection with keyword-defined collectors (Figure 4-B) to collect tweets. Event Collection can then be further split into Filtered Event Collections and Manually Filtered Event Collections. As their names implies, these other two type of collections are tweet collections with further filters placed upon Event Collections. A Filtered Event (Figure 4-C) is defined by keyword filters and is used to view a small subset of the Event Collection. The SMA-RT can also extract "Topics" (Figure 4-D) using LDA topic modeling (Blei, et al., 2003), which helps the user find sub-events or trends within a larger event. These topics are defined by certain keywords and can be added to a Filtered Event.

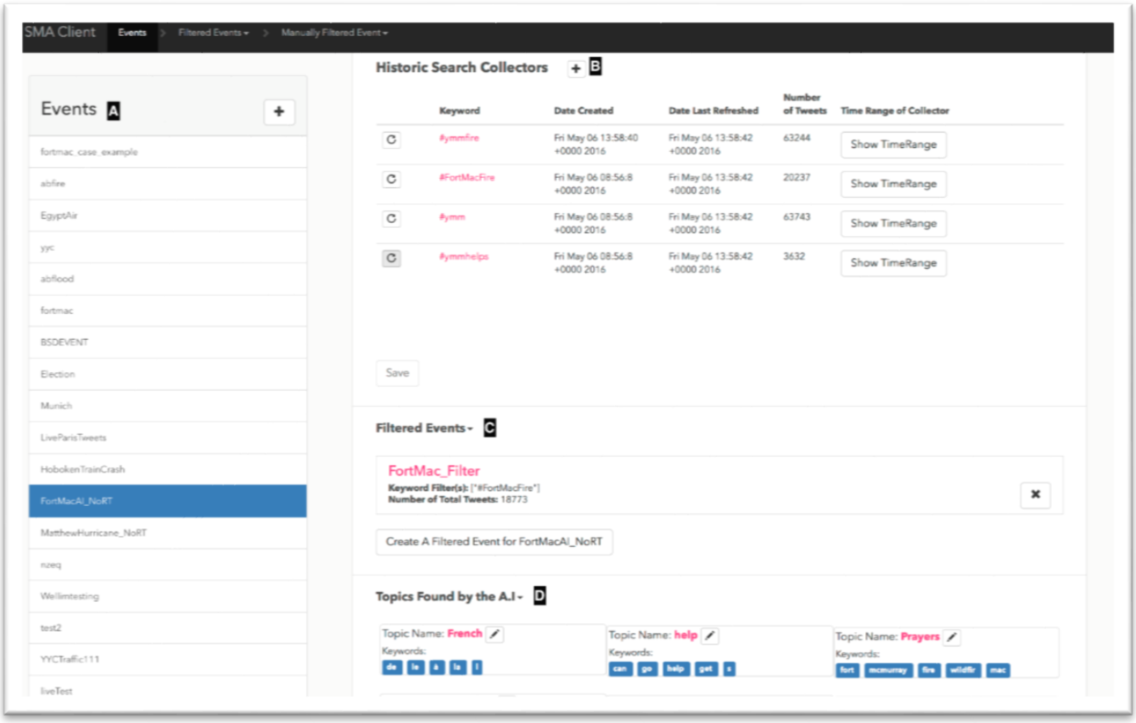

Figure 4. SMA-RT- Event Exploration. User interface for exploring events(A), create collectors to gather tweets from twitter API (B), create filtered events to filter through collected tweets (C), and extract topics from collected tweets.

Collaboration support: The pressure upon people within EOCs makes the analysis job difficult, as the responders are often local people who are also concerned for the safety of their friends and families. The participants who had experienced the Alberta floods in 2013 or the huge fire at Slave Lake in 2011 mentioned that the magnitude around those events were unprecedented. Responders may not sleep for several days and bear lots of pressure. As they stated, having a degree of separation and use the help of outsiders can be useful. For example, digital volunteers from outside the community can help in monitoring and identifying information from social media. That's why we designed web-based tool to be more accessible that supports **collaboration** between analysts and other roles in an EOC. Multiple analysts can view a filtered event and within each filtered event stream, an analyst can forward a specific post to another stream. A Manually Filtered Event allows users to manually select certain tweets from multiple events to save separately, or send off to the common operating picture of an emergency response system, such as the Emergency Operations Center of the Future, or otherwise known as EOC-F (Chan, et al., 2016). The arrow button in Figure 5-J let analyst move a tweet to either manual stream or a wall display in EOC-F.

Interactive Filtering: From interviews, we extracted that during an emergency, it is crucial that users get information quickly and accurately with easy-to-use filtering of tweets. By using machine learning classifiers to assist with this process, results can be gathered with minimal loss of time. Our design brings the human into the classification loop by letting users interact with the classifier. This solution will let users explore live streams of tweets, label incoming tweets, train the classifier and provide feedback regarding the information. It was observed that there is some resistance and mistrust for using automated filters; to address this, we ensured that our tool can work in a **manua**l as well as a **semi-automated filtering mode** and allows analysts to distinguish between machine learning and human labels. Any automatically assigned label can also be changed by the analyst if necessary. We embedded three machine learning classifiers to facilitate interactive filtering.

1) Filtering by situational awareness: We embed aforementioned SA classifier in SMA-RT. In the interface, situational awareness is tracked by a lit or unlit lightbulb symbol for each tweet, allowing for people to make quicker decisions during a time critical situation. If the SA classifier predicts situational awareness, the lightbulb symbol will have a red background to allow analysts distinguish between classifiers' output and manually labeled tweets.

2) Filtering by tagging: To facilitate categorization of tweets into user defined labels we embed a multinomial Naïve Bayes classifier using basic textual features (BoW+ TFIDF). As an example, an analyst manually tagging tweets will also train the classifier to tag similar tweets with the same tags, thus increasing the speed that information can be filtered. The automatically tagged tweets will be pink in color, and can be changed if the tag is deemed inaccurate by the user.

3) Filtering by interestingness: We can relate the interestingness of a tweet by its number of retweets (Webberley, et al., 2015). According to exploration of emergency and non-emergency tweets, retweeting increases in emergencies (Marina, et al., 2015). We attempt to identify an interestingness score in emergency context using this behavioral change. Interestingness compares the number of retweets to the predicted number of retweet counts as estimated by a classifier based on each user and tweet characteristics, and is displayed using either a yellow star for interesting, a half-yellow star for semi-interesting, and lastly a black star for not interesting (see Figure 5-J). By identifying interesting tweets, responders can ensure that no harmful rumors are circulating, and to quickly identify important details that many people have retweeted. In SMA-RT, we let users sort tweets based on their interestingness. We compare retweeting behavior between emergency and nonemergency Twitter datasets. First, we divide the tweets into different levels according to their retweet count. We grouped retweet counts in a way so that the number of tweets in each level is approximately equal. This is to prevent having small amounts of training data in less frequent levels. Inspired by (Webberley, et al., 2015) we predict that a tweet will fall into which level then we compare the predicted retweet count level for each tweet to its actual retweet count level. We train and test a predictive model (a decision tree classifier since it provided the best result among others) to predict retweet count level of a tweet based on randomly sampled data from Twitter API (Accuracy: 85.13%). For creating a predictive model, we used the following features: *Length of the text, Is the author account verified, Is there a mention in the text, Is the tweet a "reply", Is there a URL in the tweet, is there an exclamation mark in the tweet, Number of followers of the user, Number of user friends* The predictive model predicts that a tweet will fall into which retweet level. Then we apply the model on our emergency tweet dataset. As a result, for each tweet we have a predicted value and an actual value. Using (1) we infer an interestingness score for each tweet.

$$Interestingness = RT_{Actaul} - RT_{Predicted} \quad (1)$$

Where RT_{actual} is the actual retweet count interval of a tweet and $RT_{Predicted}$ is the predicted retweet count interval of a tweet using a decision tree classifier

The automated filtering process heavily depends on the users playing an involved role to help the classifier learn these trends for each individual event. There are easily accessible buttons (Figure 5-F) which allow the user to train both tagging and situational awareness classifiers. However, this process is not yet continuous and the user is required to update the training of the system whenever applicable. Although inconvenient, this re-training allows the classifier to be retrained and corrected even when information becomes more important than before.

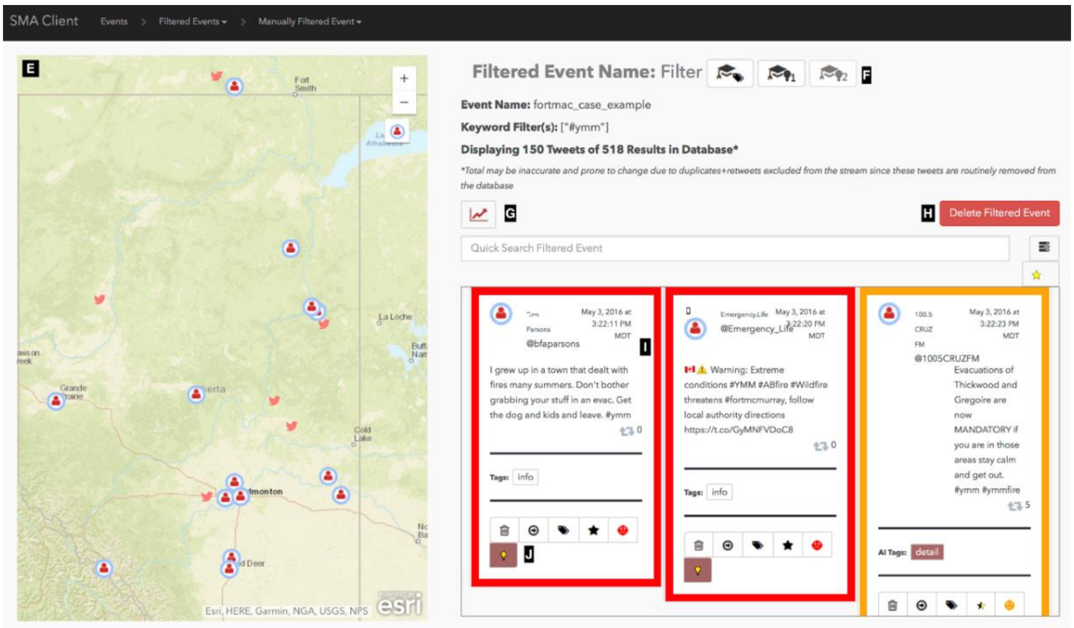

Figure 5. SMA-RT Filtered Event Page. User interface for exploration of a filtered event. Users can read and tag (J) tweets and train(F) the SA classifier iteratively.

Filtered event interface and interaction design: Simplicity in a social media tool's usage was one of the common features that the participants expected. This is especially important as depending on the emergency, personnel may decide to shift the non-trained resources to monitor social media; thus, it is important the tool would be as self-descriptive as possible. The interface was designed to be understood with minimal prior training using bold colors that standout again a clean layout. One of the participants commented that during an emergency, they usually prefer Hootsuite because of its simplicity as it displays posts in separate **stream views** that makes it easy for them to manage. Figure 5 shows a stream view, which balances displaying as much information as possible while keeping the user interface clean and easy to read. The map (Figure 5-E) shows information regarding the location of tweet, and the location of the user at the time of the tweet. If the SMA-RT extracts the location of the tweet, using the location mention extraction process, it will be red. The graduation hats (Figure 5-F) are used for training the classifier. The graph button (Figure 5-G) allows the map to be toggled off and display graphs for sentiment, interestingness, situational awareness and tags. The search bar and following buttons (Figure 5-H) can be used to change the tweets viewed within the Filtered Event. Lastly, the tweet (Figure 5-I) and the buttons below (Figure 5-J) allow quick interactions for classifying tweets and reading large amounts of tweets at once. The color of the border around each tweet displays the sentiment of individual tweets, allowing it to be easily seen.

Expert Feedback

In this section, we describe the initial feedback on SMA-RT. After developing the prototype, we conducted semi-structured interviews with 5 social media analysts we have interviewed during the design process. Our participants had at least one experience with monitoring social media in an emergency event. The goal was to understand how the system and its various elements would be helpful for social media analysts in time-critical emergency situations. At the beginning of each interview session we displayed the capabilities of SMA-RT, then proceeded to collect their feedback on the tool.

Semi-automated filters were the most controversial part of SMA-RT. There were different opinions regarding the usability of such filters. One concern that a participant mentioned was that how would junior analysts or those with limited emergency related experience know what the big picture is, such that they are able to judge what social media post is useful or not? She stated, *"Trusting people to identify information that is "important or not important" is discomforting"*. What circumstances would be worthy to set this up and use it? She stated that *"it is such a judgment call, dependent on the situation, team availability, the magnitude of the incident and whether they have the idea that the incident will "go on" long enough to benefit from the effort".* Another question was raised about how to change the filter to make previously unimportant information relevant again when the topic changes. However, participants related to public emergency organizations such as EOCs had a more positive feedback. These participants were dealing with information overload even in non-emergency situations so they realized how such filters could save them time in time-critical situations. Nevertheless, there was uncertainty towards the accuracy of such filters in the long term. One participant mentioned concerns about the possibility of the training tool misidentifying a post. He suggested that the system be "untrained" or corrected so that the same error (according to the analyst) would not appear again.

We initially designed the tool by focusing solely on the contents of the social media posts, but there was also a noticeable interest in the sources of these posts by the participants. For example, they would like to see aggregated information regarding a source with just one click or by hovering over a person icon. Such information like description, number of tweets, number of followers and followings would be helpful, they would also like to know if the person is linked to any other person in their network. They would be able to use all this information to infer reliability of a person, which is also lacking in their current tools. They also would like to pull posts based on specific users. Another addition would be to allow the ability to add a user to their "follow list" or list of reliable and unreliable users that they want to keep track of and perhaps use in future streams. Another participant suggested that they want be able to "silence" people so they don't keep populating your stream if this person is not worth "listening" to. One participant also suggested that if they could manually set the "reliability" for a user.

CONCLUSION AND FUTURE WORK

Social media has brought new opportunities and challenges in response to emergency events; the widespread usage of social media has made it difficult for analysts to extract their information needs from the data. Current commercial tools that are being used by analysts do not let users prioritize the social media posts based on their importance or the level of information. In this paper, we propose a machine learning classifier to identify SA tweets using textual, social, location, and tone based features to increase precision and recall of SA tweets. We take a human centered design approach to developing a visual analytics prototype (SMA-RT) to bring social media analysts in the classification loop and increase their task performance. The SMA-RT interface combines the ability to collect, search and sort tweets alongside the functionality to filter and organize them with machine learning techniques. SMA-RT allow analysts to filter tweets based on their situational awareness, tagging, and retweeting beyond expectation (interestingness). It also helps analysts to locate tweets if there is a location mention in the text. Initial feedback on the core parts of tool was positive.

We plan to conduct a usability study for the proposed visual analytics tool and thus evaluate the tool using social media analysts that have interviewed during the design process. The goal is to evaluate their task performance based on the amount of time these analysts will spend to gain the target information, how much information they will collect, how well they achieve the predefined goals behind each task, and lastly, how satisfied they will be with the tool.

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Rumors, Fake News and Social Bots in Conflicts and Emergencies: Towards a Model for Believability in Social Media

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ABSTRACT

The use of social media is gaining more and more in importance in ordinary life, but also in conflicts and emergencies. The social big data, generated by users, is partially also used as a source for situation assessment, e.g. to receive pictures or to assess the general mood. However, the information's believability is hard to control and can deceive. Rumors, fake news and social bots are phenomenons that challenge the easy consumption of social media. To address this, our paper explores the believability of content in social media. Based on foundations of information quality we conducted a literature study to derive a three-level model for assessing believability. It summarizes existing assessment approaches, assessment criteria and related measures. On this basis, we describe several steps towards the development of an assessment approach that works across different types of social media.

Keywords

Social media, believability, measurement.

1. INTRODUCTION

The increasing use of social media promotes, and even requires, new kinds of cooperation and collaboration between authorities, citizens and media in exceptional situations such as emergencies or large-scale crises. On the one hand, citizens demand current situational information by authorities and media, but citizen-generated content might also contain valuable information for the formal process of crisis management (Palen, Vieweg, & Anderson, 2010, p. 2f). In any case, the believability and reliability of used information play a crucial role to prevent the propagation or processing of misinformation such as fake news and rumors (Gupta, Lamba, Kumaraguru, & Joshi, 2013). With the emergence of "social bots", the topic becomes even more important: These bots are used in social media such as Facebook, Google+ or Twitter to publish information using specific hashtags or retweeting information of specific authors, and are often disguised as regular users with profile pictures, posts and followers. For instance, political bots are used to manipulate the public opinion (Ferrara, Varol, Davis, Menczer, & Flammini, 2016), which can also be used to carry out conflicts between countries.

A body of work already examined the assessment of information on the internet (Friberg, Prödel, & Koch, 2010; Ludwig, Reuter, & Pipek, 2015; Reuter, Ludwig, Kaufhold, & Pipek, 2015; Wang, Strong, & Guarascio, 1996), whereby *believability* is always mentioned as an important component of information quality. The aim of this paper is to explore existing approaches and criteria for assessing information believability in social media, to analyze their potential uses and finally to combine appropriate methods to realize a preferably reliable assessment of the believability of citizen-generated information. Such an approach is ideally supposed to be automatable to enable a consistent and quick assessment and to facilitate a manual screening of (mass) information. To achieve these goals, the paper introduces the basic context and terms (section 2) and presents, rates and analyzes existing approaches and criteria for assessing information believability within a systematic literature study (section 3). These approaches and criteria were used to develop a novel assessment method for information believability (section 4). Finally, the closing discussion outlines limitations and potentials of assessing the believability of citizen-generated content in social media (section 5).

2. FOUNDATIONS: QUALITY CRITERIA OF CITIZEN-GENERATED INFORMATION

Many papers have already considered most of the different criteria and partial aspects of information quality. Since the focus of this article is on a partial aspect of information quality, namely the believability of information, only a rough overview is given. The terms data quality and information quality are used synonymously here because information is only gained through data processing (Huang, Lee, & Wang, 1999, p. 7), but it is not assumed that citizens distribute data consciously to provide as many people as possible with information. Furthermore, the believability of data is considered, supposing that other quality criteria are met to enable an accurate further use concerning information. Accordingly, implausible information is equivalent to implausible and thus useless data.

Wang et al. (1996) define believability as follows: “The extent to which data are accepted or regarded as true, real, and credible”. To this date, there is no uniform definition of the term believability, but it is broadly recognized that believability results from a combination of the sender’s, message’s and recipient’s attributes (Wathen & Burkell, 2002, p. 2). The measuring of the quality criteria of information is a challenging task since it must be as exact as possible and simple to apply in practice. These goals are conflictive (Naumann & Rolker, 2000) so that a compromise between both conditions must be found. Thereby, the relation in which the specific condition has to be fulfilled can vary (e.g. exact acquisition vs. saving costs).

Although this paper focuses on citizen-generated content in social media such as Facebook, Twitter and Google+ (Boyd & Ellison, 2007), the believability of information plays a crucial role in every field since only credible information are taken into account by the user (Gräfe & Maaß, 2015, p. 173). Hiltz et al. (2011) also consider the assurance of believability and trust an important challenge while using social media. They also emphasize the development of an automated assessment mechanism for separating credible and implausible information as a necessary future step while using information from social media, especially related to disaster situations and emergency service employments. Ludwig et al. (2015) argue that “in dynamic situations of this kind, the fit of information to specific tasks is more important than generic assessments of information quality.” Knowing that information quality is calculated differently across possible scenarios (Christofzik & Reuter, 2013), Reuter, Ludwig, Ritzkatis and Pipek (2015) provide a “tailorable quality assessment service (QAS) for social media content” that allows the different criteria to be adjusted according to the situation’s and user’s requirements. Besides believability, a close research field examines the detection of rumors. The PHEME project (https://www.pheme.eu/), for instance, published a preliminary annotation scheme for social media rumours by analyzing the source tweet (polarity, modality, evidentiality, and author type) and response tweets (modality, evidentiality, author type, and response type) with the goal of training a model for automatic rumour detection.

Since the application of social media also increases consistently in disaster situations and even emergency services count more and more on the use of social media to spread or get information (St.Denis & Hughes, 2012), the use of fake news, which comprise fabricated, imposter, manipulated and misleading content, e.g. consciously through click baiting (Chen, Conroy, & Rubin, 2015), as well as satire, parody, false connections and false contexts, can have serious consequences in such situations (Wardle, 2017). Moreover, the time factor plays a major role in disaster situations (Palen et al., 2010) so that there is often no time for a manual screening and assessment of social media posts. To reduce the risk of misjudging information, this paper is supposed to provide a possibility to sort or screen posts by means of their believability by combining various, existing approaches and criteria for the assessment of the believability of user-generated information.

3. LITERATURE STUDY

3.1 Methodology

We conducted a literature study to identify and analyze, in terms of their suitability concerning the study’s aims, concepts and criteria that serve for the assessment of believability to encourage the development of an assessment approach. Using the terminology and framework of vom Brocke et al. (2015), we approached the field with a systematic literature review which is “a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners” (Fink, 2010). We applied the *sequential* process comprising the steps of input (searching), processing (analyzing, synthesizing) and output (writing). Our sources contained *bibliographic databases* (University Library, Google Scholar and Bielefeld Academic Search Engine (BASE)) and known *key publications*, which shaped the process of the literature review. In terms of coverage, our aim was not to collect a comprehensive sample of publications in the field of information quality, but to focus on *seminal works* on the believability of social media content. Furthermore, we applied the techniques of *keyword search*, using a keyword list for the search for German and English-speaking literature, and *backward search* to obtain further relevant works from references of the collected papers.

We used the following German and English words: *Authentizität; authenticity; believability; bürgergenerierte Informationen; citizen generated information; collective intelligence; credibility; Eigentrust; Glaubwürdigkeit; intrinsic information quality; intrinsische Informationsqualität; kollektive Intelligenz; reliability; Social Media; Soziale Netzwerke; trustworthiness; user-generated-content; Validität; validity; Web 2.0*

The paper of Palen et al. (2010) turned out to be one of the most important publications. None of the papers within the literature study provided an appropriate cross-platform assessment approach. Therefore, this paper is supposed to be the first step towards a uniform assessment approach for citizen-generated information in social media. It intends to give an overview of the challenges of its practical realization.

3.2 A Three-Level Model for Assessing Believability of User-Generated Information

The analysis of existing papers reveals that the presentation of the landscape of assessment approaches and criteria for user-generated information takes place on three levels. Therefore, we developed a three-level model to get a better overview of the existing ideas and tools and to create a clear foundation for the following sections (Figure 1). First, there are existing practical applications that implement assessment models for certain social media which build the highest level of existing assessment approaches (level 1). These models, in turn, make use of specific assessment criteria, which can have an influence on the believability of information (level 2). The lowest level comprises possibilities for examining criteria of level 2 and plays a rather subordinate role since the aim of this work is a combination of various criteria and approaches for the assessment of believability and not the assurance for the correctness of the considered aspects (level 3).

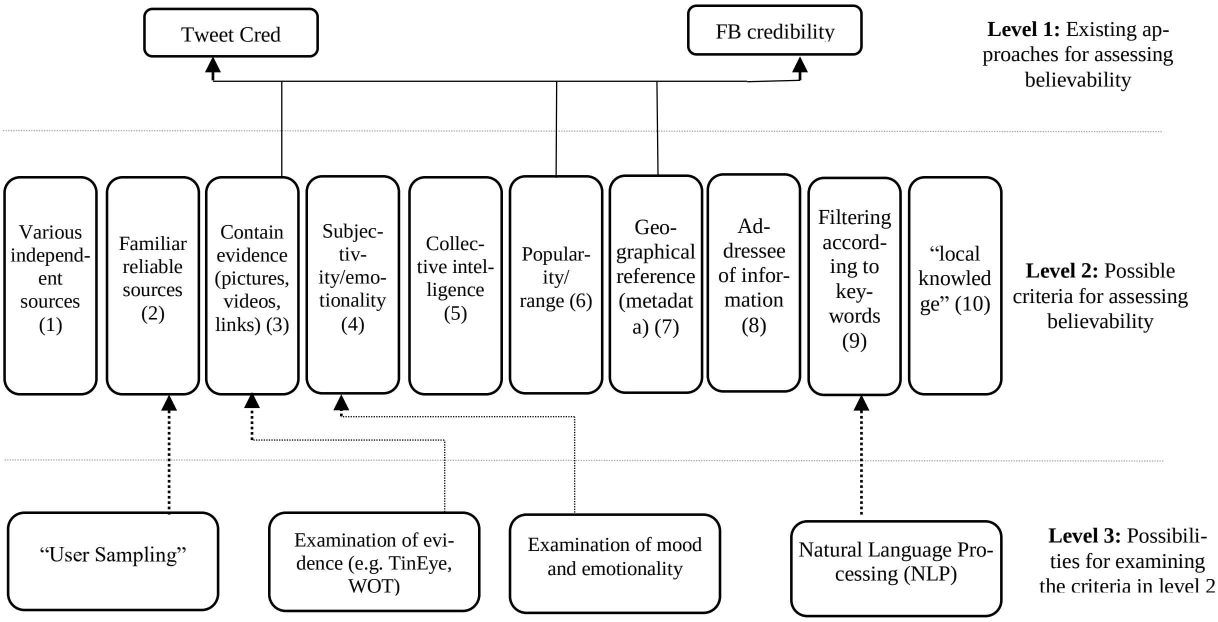

Figure 1. Three-level model of existing approaches for assessing believability

3.2.1 Level 1: Existing Assessment Approaches

Some of the identified criteria are already part of existing assessment approaches for the believability of social media posts (level 1, Figure 1). *TweetCred*, for instance, is a tool for real-time assessment of believability which also allows the examination of the trustworthiness of content on Twitter (Gupta, Kumaraguru, Castillo, & Meier, 2014). The system is based on the concept of semi-supervised learning and initially was trained through the manual classification of tweets concerning their situation reference and their believability. The SVM-rank algorithm for assessing the believability of tweets considers 45 characteristics in seven different categories in total. The access to the used tweets is realized with the help of the Twitter API. There are some parallels between the ten criteria visualized earlier (Figure 1) and the criteria named by Gupta et al. (2014).

A similar tool, *FB credibility*, is also available as a browser plug-in and was developed by Saikaew and Noyunsan (2015). It evaluates the believability of Facebook posts by means of the following criteria: *(1) number of likes, (2) number of comments, (3) number of shared posts, (4) number of contained links, (5) number of pictures, (6) number of hashtags, (7) number of videos, (8) availability of geographical metadata (location information).* Seven of these eight criteria, which were collected in the literature study, are covered; only the number of hashtags is added. First, the applied algorithm needs to be trained with the help of manually assessed posts. Since the Facebook API does not grant a sufficient access to the required data, the collection is realized with an own JavaScript code. For the assessment, a scale from 1 (implausible) to 10 (believable) is used. TweetCred and FB credibility further allow users to indicate their agreement on the computed believability value.

In a study, 81% of the users of FB credibility agreed to its assessment of believability (Saikaew & Noyunsan, 2015). While Saikaew and Noyunsay (2015) used eight criteria for their assessment of believability and got 81% agreement by the users, Gupta et al. (2014) took 45 criteria into account and got 40% agreement even though the information were more believable than they were rated. This shows that the use of more criteria does not necessarily result in a more reliable assessment of believability. Nevertheless, it makes sense to improve the named criteria since the examination of the respective criteria cannot take place consistently across media anyway.

3.2.2 Level 2: Assessment Criteria

Based on the literature review and on existing approaches, assessment criteria were analyzed and selected in terms of their relevance for believability in the context of social media. Overall, ten specific criteria constitute the second level of the three-level model:

1. **Various independent sources**: Several sources provide the same information (Palen et al., 2010; Rieh & Hilligoss, 2008, p. 14f): examination through so-called *cross-checking*, i.e. search for additional sources of similar content.
2. **Famililar and reliable sources:** The source is known and trustworthy (e.g. emergency services, Trusted Volunteers, transitive trust or the like) (Kamvar, Schlosser, & Garcia-Molina, 2003; Naumann & Rolker, 2000; Palen et al., 2010): Examination of trustworthy persons can be made through a database or *transitive trust*, i.e. the classification of trustworthy senders through reliable individuals.
3. **Contain evidence:** The source contains evidence such as pictures, videos, links to official sources or the like (Castillo, Mendoza, & Poblete, 2011, p. 7f; Oh, Kwon, & Rao, 2010, p. 12; Palen et al., 2010): Examination on content-related correctness about the attached evidence.
4. **Subjectivity/emotionality:** Filtering according to keywords – determination of subjectivity and emotionality (Castillo, Mendoza, & Poblete, 2013, p. 12; Oh, Agrawal, & Rao, 2013, p. 3f): Check text quality, because many orthographic or grammatical mistakes speak for a low believability, for example.
5. **Collective intelligence:** Correction of information through collective intelligence (Mendoza, Poblete, & Castillo, 2010; Palen et al., 2010; Vieweg, Palen, Liu, Hughes, & Sutton, 2008): Information might be examined through comments, corrections of the author, or questions of other observers, reducing the spread of misinformation (reference to criterion 6).
6. **Popularity/range:** Popularity and range of information – e.g. number of “likes”, “shares” (Facebook) or “Followers” (Twitter) (Castillo et al., 2011; Palen et al., 2010): The believability of contained information increases due to the pre-filtering through subjective assessment of disseminating users.
7. **Geographical reference**: Geographical proximity or another personal reference to the content (Gupta et al., 2014, p. 8; Oh et al., 2013; Palen et al., 2010): Believability results from the (personal) interest in trustworthy information by the author (e.g. search for help) due to physical proximity or belonging to organizations, communities or the workplace.
8. **Addressee**: Is information addressed to the public or particular persons? Existing concepts “imply that a rumor is more likely to spread within a community (i.e. particular persons) that is sustained by affective trust and strong social ties” (Oh et al., 2013, p. 412).
9. **Filtering keywords and signs**: Is specific information often questioned or disputed? Are there special symbols often used such as question marks or exclamation marks? (Castillo et al., 2013; Mendoza et al., 2010). Questions, doubts, or positive statements (combination of 4 & 5) influence believability positively or negatively. The use of many special signs, such as question marks or exclamation marks, can be a sign for lower believability.
10. **Existing “local knowledge”**: Local details, which outsiders maybe do not know and which signal the own consternation and thereby serious interest in misfortune (Palen et al., 2010): The believability results from the high geographical reference (e.g. knowledge of recent incidents, special buildings), the examination possibly proves to be problematic.

Within these assessment criteria, a conflict can result between the criteria 6 and 8 if popular members of social media spread generally accessible posts, for example. Furthermore, Oh et al. (2013) state that there is a restriction in situations, in which the author or the propagator of messages is worried or anxious. That questions the effectiveness of the collective intelligence (criterion 5) as well as the validity of the range and popularity of information (criterion 6) in connection with their believability in specific and time-sensitive situations (Oh et al., 2013). Naumann and Rolker (2000), for example, take the believability of information for not automatically assessable since the assessment of believability is always subjective and depends on the respective user of the data. Therefore, subjective quality criteria, such as believability, can only be measured for an individual person. This implicates that the assessment mechanism must be individualized for every user profile. This restriction for automating information assessment shows that a universal solution for automated assessment of believability is hardly realizable and an individualization should be allowed.

3.2.3 Level 3: Examination of Assessment Criteria

The work of Naumann and Rolker (2000) states three options for assessing subjective criteria: (1) *User Experience* (cf. approach 2), (2) *User Sampling* (from experiences of previous assessment as well as several articles of particular unknown sources), (3) Continuous User Assessment. Starbird et al. (2012) provide another example with their work about the determination whether an article was written on-site or by an outsider. This can be helpful insofar that the proximity to the affected area speaks for a higher believability than a spatial distance to the place of action. Using *SentiWordNet*, texts can be evaluated concerning their mood or predominant opinion (Pang & Lee, 2008, p. 111). Thereby, the three categories “positive”, “negative”, and “objective” are distinguished. With *OpinionFinder,* Wilson et al. (2005) present a system which consists of four components for analyzing subjectivity in texts. With that, opinions, moods and other subjective aspects can be identified.

Besides the examination of emotionality, texts can also be filtered for certain thematic orientations and keywords using *Natural Language Processing (NLP)*. Moreover, spelling and syntax mistakes can be realized and corrected. The possibility of multilingual filtering of texts is also interesting for the cross-platform social media application (Chowdhury, 2003, p. 22f). The examination of the quality of linked websites can be facilitated with the help of Web of Trust (WOT), for instance. This platform for assessing websites shows users to what extent previous users of this website take it for trustworthy. The assessment, in turn, is based on the believability criterion of collective intelligence (criterion 5).

4. TOWARDS THE DEVELOPMENT OF A CROSS-PLATFORM BELIVABILITY ASSESSMENT APPROACH

4.1 Preliminary Considerations and Selection of Assessment Criteria

The previous section shows the complexity of developing a suitable algorithm for believability assessment due to plenty of factors: First and foremost, believability is subjective and users follow different interests in the exploitation of information and have different views on information. There are different claims for believability values (absolute trust required - e.g. emergency services - versus lower claims for the information search - e.g. private research with no time pressure and the possibility to examine believability) and users may consciously or unconsciously spread misinformation. Moreover, there are many assessment criteria, which are partly difficult to measure, context-dependent and difficult to weight. In this regard, different platforms with various conventions (hashtag-syntax, followers, likes, friends, focus on pictures/videos, etc.) and different numbers of users and posts constitute challenges in the definition of an algorithm. Also, there are differences between the availability of data; for instance, the Twitter API provides broad access to public data, but the Facebook Graph API offers only reduced access due to the larger proportion of private structures. Thus, also data protection issues must be considered (saving of user data of reliable sources, use of photos, videos and user information).

Because not every discussed criterion is applicable to every social medium, it is obvious that one should use platform-independent criteria. However, the notions and specifications of the used assessment criteria differ in some aspects so that an apparent commonality cannot be determined for certain. Furthermore, the existing tools are limited to two social media platforms, which have some parallels so that the type of contents (text, pictures, videos), the structure of social contacts (friends, followers, subscribers, etc.), and the formal conditions of the respective platform (character limit, required syntax) additionally should be considered for contents for further platforms. Therefore, it will not be possible to determine the criteria exactly, which can be applied to all social media equally. Hence, the selection of the suitable criteria is made in general terms and must be inspected for concrete possibilities for the implementation.

Based on the literature study and the presented existing tools, the three most mentioned criteria for the assessment are the range/propagation of the posts, the availability of reliable sources and evidence (pictures, videos, URLs) and geographical or content-related reference. These criteria can be fulfilled cross-platform and partly collected in many social media. Further criteria are the emotionality or mood of the posts (4) and the filtering by relevant and significant keywords (9). Using NLP, one can also identify content-related parallels (Brill & Mooney, 1997, p. 5) between posts to find several sources to proof the believability of the texts (1). One possibility which can be applied to all social media is the management of known and reliable sources. Although correcting false information by collective intelligence (5) seems to have a positive effect on the believability, it cannot be measured actively as it is a passive mechanism. The availability of *local knowledge* is not considered as an independent criterion since the mentions of actual true local circumstances cannot be examined reliably. The aspect is covered by the local connection (7) regarding the non-geographical reference and is proved insofar that the posts, which contain the same information (1), confirm it. Figure 2 reflects the selected criteria for the further procedure.

4.2 Modeling the Possible and Negative Effects of the Assessment Criteria

Figure 2 shows the potential positive ("+") and negative ("-") effects of the selected criteria. While a high range and reputation (e.g. likes) always affect believability positively, most of the other criteria can have both positive and negative effects. Existing proofs for the spread contents can have negative effects if they are dubious, old or implausible. Especially examining the quality of photos and videos is difficult since the content is not made automatically. Therefore, three possibilities are distinguished. Known helpful data can have positive effects on believability since they present a (positive) content-related overlap with other sources (VII) and contain believable evidence. If a photo turns out to be known but implausible or too old, the believability is effected in a negative way. If none of these two situations arises, one deals with an unknown evidence, which must be proved manually. Additionally, the geographical proximity signals interest in this location and therefore raises the believability.

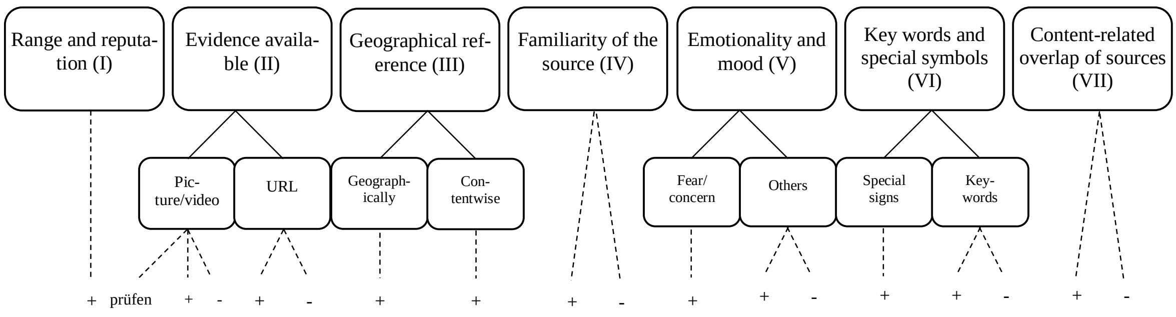

Figure 2. Criteria for assessing believability in social media and effects

The publicity of a source cannot only have positive effects on the believability of contents, but also save bad experiences with certain users in social media, e.g. if someone distributes dubious posts regularly. However, there should be regular examinations of the classification of believability for trustworthy and implausible sources since the assessment may change. Other persons can use user accounts; accounts can be hacked. While the literature study showed that fear and anxiety of the authors of citizen-generated posts in social media could have negative effects on the believability, other emotions and moods can have positive effects (Castillo et al., 2013). Moreover, a frequent mention with same content can have a positive effect on the believability of information whereas contradictions can lead to a downgrade of believability.

4.3 A Proposal for the Cross-Platform Assessment of Believability

The assessment of believability might be realized by weighting the identified criteria (Figure 2). The level of influence on believability is different between the individual criteria for various reasons. First, these are measurable cross-platform to different degrees. However, more important is the scaling of the individual measurement results. A geographical reference in a post can either exist or not, range and reputation can be available to different degrees. Further points of reference are the reliability for the measuring and its practicability. If the post contains a URL or a picture, it regularly speaks for high believability. On the contrary, it is not clear how great the impact of emotionality and mood is in terms of believability and therefore must be examined and adapted by unknown factors implementing further examinations.

These considerations determine the ranking of the individual assessment criteria. According to that, the familiarity of the source (IV) has the greatest impact on believability. In the second place, the examination of evidence follows, especially containing URLs, which ideally enable a verification of the information. Additionally, it has synergies to criterion VII since, once examined, evidence is saved and its reliability can be determined directly in case of recurrence if posts show parallels when using evidence. Subsequently, range and reputation of a post follow in the ranking of impact on the believability value, as they are easy to measure, compare and scale. The content-related overlap of sources regarding mutual confirmation or contradictions is ranked fourth. The geographical reference is ranked below since not every post refers to a location. Therefore, a lower relevance of this criterion serves the comparability of posts of various platforms. If one classified a tweet about a catastrophe as significantly more credible because it contains a suitable geographical reference, it would potentially for no reason be classified as more credible than another post from a platform, whose content does not have a geographical reference. Finally, the criteria follow which evaluate texts by emotionality, mood, keywords and special signs. On the one hand, the possibility to evaluate such criteria is unequally distributed on social media since a few platforms are specialized on the sharing of pictures or videos (YouTube, Flickr), while others rather focus on text messages (Twitter) or support different information carriers (Facebook). Moreover, the exact consequences and their scaling on believability are not as clear as the ones of other criteria of believability. Thus, based on the study and our argumentation, the following list of criteria results:

1. Familiar sources evaluated concerning their believability (IV)
2. Information is proved with evidence such as pictures, videos or URLs (II)
3. Range and reputation of a post (I)
4. Content-related compliance between posts (VII)
5. Geographical reference (III)
6. Filtering by keywords, emotionality, mood and special signs (V, VI)

Another point is the assessment of absent criteria. It is obvious that the absence of positive criteria cannot be evaluated positively. However, the lack of evidence does not mean that the information is automatically implausible. Therefore, an assessment is suggested, which uprates posts fulfilling positive criteria; however, the assessment of these posts, which do not fulfill the criterion, should not suffer. Thus, the absence of positive criteria does not affect the assessment of believability. Consequentially, posts, which do not meet any of the criteria, whether positive or negative, receive a neutral assessment of believability.

To evaluate the practical suitability of the developed cross-platform approach concerning the evaluation of believability in social media, the following steps must be executed: Initially, there should be a possibility to collect and unify relevant posts for the evaluation of believability in various social media so that they can be evaluated similarly. Existing SVM algorithms are suitable for adapting the evaluation of believability. After realizing technical aspects, such as the possibility to manage familiar sources and to implement various criteria from level 3 (see Figure 2), the algorithm's realization (e.g. scoring of criteria, behavior on absent criteria) and evaluation can be executed. While the two presented existing evaluation approaches are implemented in the form of browser plug-ins, and TweetCred is additionally offered as a web-based application and API, the question regarding technical potentials and the meaningful implementation of such an approach arises.

5. CONCLUSION AND OUTLOOK

This paper has shown that assessing believability, especially in cross-platform fields, has hardly been addressed yet and therefore requires several developments until a suitable assessment mechanism is realized. An important first step in this direction is the conception of a possibility to collect and standardize data cross-platform to enable the filtering of data for a believability assessment using a scoring algorithm. Furthermore, the implementation of the assessment approach implies obstacles, for instance, technical challenges such as the realization of the individual believability criteria and the procedures for their examination. Moreover, such an algorithm should support the selection of individual assessment criteria and the adjustment of their weightings to enable an individualization of the assessment of believability, which – especially during conflicts and emergencies – depends on the situation, purpose, persons, and role. Furthermore, the proper procedures for the examination of believability criteria must be selected and developed. Regarding the technical implementation, further aspects have to addressed, for example, the question concerning the data protection or the liability for wrong decisions (St.Denis & Hughes, 2012).

Currently, there are several developments in the field of assessing believability in online communities, which indeed are limited to certain platforms, but still could gain many findings in the field of assessing believability in social media. These findings represent a part of the preparatory work for developing a cross-platform assessment approach for the believability of citizen-generated information in social media. This paper shows a further step in this direction through conceptualizing a general approach for cross-plattform believability in social media and provides a first theoretical recommendation for action for the realization of such a solution. However, to implement and refine such an approach, it must be carfully synchronized with social trends and research proceedings in the fields of information quality (Shankaranarayanan & Blake, 2017) and validation, rumor detection (Mendoza et al., 2010) and social bots (Ferrara et al., 2016).

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Monitoring disaster impact: detecting micro-events and eyewitness reports in mainstream and social media

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ABSTRACT

This paper approaches the problem of monitoring the impact of the disasters by mining web sources for the events, caused by these disasters. We refer to these disaster effects as "micro-events". Micro-events typically following a large disaster include casualties, damage on infrastructures, vehicles, services and resource supply, as well as relief operations. We present natural language grammar learning algorithms which form the basis for building micro-event detection systems from data, with no or minor human intervention, and we show how they can be applied to mainstream news and social media for monitoring disaster impact. We also experimented with applying statistical classifiers to distill, from social media situational updates on disasters, eyewitness reports from directly affected people. Finally, we describe a Twitter mining robot, which integrates some of these monitoring techniques and is intended to serve as a multilingual content hub for enhancing situational awareness.

Keywords

Natural language processing, machine learning, crisis computing, disaster effects, social media

INTRODUCTION

Natural disasters have caused a total of $1.5 trillion in damage worldwide between 2003 and 2013, according to a study by the United Nations Food and Agriculture Organization (FAO), which finds they caused more than 1.1 million deaths and affected the lives of more than two billion people[1]. Effects of the disasters range from tragic loss of human lives and injured people to interrupted services, damage of infrastructures, as well as shortage of basic resources.

It is nowadays well recognized (Vieweg et al. 2010) that spreading real-time information about the damages caused by the disasters, as well as about the ongoing response measures on the field, can significantly contribute to the relief process and mitigate the overall impact, by enhancing Situational Awareness of stakeholders (victims, responders, donors).

When a heavy disaster hits a region, usually people rely on online mainstream media, radio and TV to look for updates about the situation in their surroundings. Social media have a very important role during such events, since people share real-time information about ongoing developments and at the same time seek for situational

[1] http://www.fao.org/3/a-i5128e.pdf.

updates from response organizations or other users. Unfortunately, tracking the descriptions of damages in online media is a challenging task, because of the overflow of information available, as well as the overlapping descriptions of the same facts, and even more in social media where language variation, re-posted, irrelevant or unreliable content are pervasive.

This paper addresses the problem of detecting natural disaster-related *micro-events* in online mainstream and social media sources. As micro-events caused by natural disasters, we consider casualties (dead, injured, trapped people), destruction or damage on buildings and other infrastructures, disruption of transport and other services, shortage or provision of resource supplies such as electricity, water and fuel, as well as recovery work and operations for rescuing of people. The term *micro* refers to the local consequences of such events – a damaged building or interruptions of service usually affect a small fraction of the local community. We propose solutions for automatic learning of grammar models for micro-event detection and apply these models in a real world application detecting micro-events in tweets published during natural disasters.

First, we present a novel algorithm for learning of event detection grammars. We then describe how we use it to induce in an unsupervised manner a grammar for detecting disaster-related micro-events from online media sources, starting from an unannotated news corpus. To the best of our knowledge, there are no other machine learning approaches which target the detection of such micro-events in news. We also describe the creation of a news corpus annotated for micro-events, which we use for evaluation.

Afterwards, we describe a similar algorithm that, by using weak supervision, is able to learn, from social media data, event patterns categorized into a predefined set of disaster-related event types. The resulting grammars can be used to "make sense" of the large mass of messages exchanged by social media users during disasters, namely for discarding the large fraction of off-topic content, and further classify the disaster related messages. The method is multilingual and has shown high accuracy in extracting micro-events from a stream of Twitter status messages.

Social media have been described as being used as an information "multichannel" during disasters: the general public seeks for official updates from authorities as well as personal updates from their communities, while response agencies disseminate critical information to the public and try to gather crowd-sourced situational updates from the field (Imran et al. 2015). We focus here in the latter type of social media messages which are often referred as "eyewitness content" and we define it as "information originating from eyewitnesses to the event or to response/recovery operations, or from their family, friends, neighbours", from (Olteanu et al. 2015).

The frequency of eyewitness reports on social media during disasters largely varies across events and event types. (Olteanu et al. 2015) asked crowd-sourced workers to annotate for an attribute "Information Source" around 25000 tweets from a set of 26 events, including natural hazards and man-made disasters. They found an average of 9% status messages reporting eyewitness accounts. A similar analysis we performed on a small sample (200 tweets) of a corpus collected for the August 2016 Central Italy earthquake[2] confirmed this finding: 8.7% of the tweets categorized as "Infrastructure Damage" were eyewitness reports, while 92% in the same category were considered Informative messages. Therefore, we believe that being able to distil eyewitness situational updates out of the vast majority of news media and institutional content echoed through social media and to re-direct it to target recipients may help accelerating the information flow and the overall response process. We tackle this task by deploying statistical Machine Learning classifiers, trained on data from previous disaster events.

Finally, we describe a simple Twitter channel that integrates most of the techniques described above: it dynamically tracks target disaster events by filtering, tagging and re-posting Twitter status messages, serving as a social media content hub for situation monitoring and impact assessment.

RELATED WORK

The grammar learning method is based on a previous algorithm presented in (Tanev, 2014). We have reported similar work on Social media in (Tanev and Zavarella, 2013). Disaster-related terminology was the focus of different previous studies, such as (Thywissen, 2006) and (Gunn, 2003).

Automatic detection of natural disasters and other security-related events was discussed in previous

[2] https://en.wikipedia.org/wiki/August_2016_Central_Italy_earthquake

publications, such as (Piskorski et al., 2011). Event scenario template filling was introduced as a task at the Message Understanding Conference (MUC) (Grishman et Sundheim, 1996) for a description of this task. Exploitation of social media for enhancing the information extracted from online news was discussed earlier in (Tanev et al., 2012). Most of the work on event detection from social media focused on English language only, a noticeable exception being (Zielinski and Bügel, 2012).

Algorithms for grammar induction were presented in different publications, look at (Palka and Zachara, 2015) and (Athanasopoulou et al., 2014) among the others. A survey of grammar induction approaches is presented in (D'Ulizia et al., 2011).

The usefulness of social media during disasters was discussed in (Lindsay 2011; Fugate 2011), (Howell et al., 2011) and others. Many publications discuss the automatic analysis of Twitter messages, published during disasters. Most of the work focused on message retrieval, classification, extraction of information, aggregation: see among the others (Imran et al., 2013, 2015) and (Middleton et al., 2014).

Within this field, a number of attempts have been performed to capture first-hand situational reports from disaster affected areas. Among computational models, (Morstatter et al., 2014) have approximated our task with the one of detecting tweets originating from within the region of the crisis, by analysing the linguistic features that differentiate them from the ones from outside the region. They could automatically collect annotated training data by relying on tweet geocoding metadata, however their definition of eyewitness is incompatible with ours. (Verma et al., 2011) explored the non-equivalent task of automatically identifying tweets for situational awareness (SA). They used a combination of shallow language features and the output of a number of classifiers, for Subjectivity, Personal/Impersonal, etc.

(Fang et al., 2016) present an experiment where they trained a SVM classifier on a large dataset extremely skewed towards negative instances (118K vs. 400); their feature set is partially overlapping with ours, but they additionally integrated 300 dimension Word Embeddings for each word in the tweets, computed from a 198M tweet corpus, which dramatically increased the performance. (Pekar et al., 2016) contains an empirical feature analysis of a classifier most similar to ours and ran on the same dataset; we built upon their empirical findings in our approach.

UNSUPERVISED LEARNING OF EVENT DETECTION PATTERNS

Method

We have developed an unsupervised algorithm for learning of grammar rules which is based on the algorithm presented in (Tanev, 2014). Our algorithm has the following basic steps:

1. Take a text collection *C* whose main topic is from a given domain (in this case natural disasters)

2. Find a set of terms *T* with the highest TF.IDF in the disaster-specific text collection *C*. TF.IDF returns the terms which are frequent in this domain-specific collection, but otherwise are rare in other texts. These terms are characteristic terms for the disaster domain. As an example, let's consider the *T* being the set *earthquake, floods, damaged, destroyed facilities, schools, universities, church, destroyed, damaged, flooded, collapsed, toppled,* etc.

3. Following the grammar learning algorithm described in (Tanev and Zavarella, 2013) we generate grammars from the terms in *T* and the news article corpus *C*.

a. Represent the terms from *T* as distributional feature vectors, whose dimensions are the n-grams appearing immediately on the left and on the right of the terms.

b. Cluster the terms, using the cosine similarity between their feature vectors. In this way words which appear in similar contexts will finish in the same cluster. According to the Harris' distributional hypothesis, those words that occur in the same contexts tend to have similar meanings. Following our toy example, the terms in *T* will form two clusters *T1*={*earthquake, floods*}, *T2*={*damaged, destroyed, flooded, collapsed, toppled*} and *T3={church, universities, school, facilities,…}*.

c. Find the pairs of clusters whose terms co-occur in the domain specific corpus *C* next to each other or are divided by prepositions and other stop words. Let's assume that in the corpus *C* we have the phrase *earthquake damaged*. Since *earthquake* belongs to the first cluster *T1* and *damaged* to *T2*, then a generalization pattern

[T1 T2] will be derived among the others.

d. Select only the rules which are composed of a cluster containing verbs and a cluster which does not contain verbs. The goal of this step is to leave only event detection rules. This constraint is novel with respect to the original algorithm.

e. Create a finite-state grammar rule from each selected word cluster pair. In order to provide higher recall, the grammar rules allow for a couple of additional alphanumerical tokens between the terms from the cluster pairs.

The logic behind this algorithm is the following: By capturing just the pairs of terms which have high TF.IDF for the specific collection, we are getting phrases which are specific for this text collection. Moreover, we limit ourselves to the phrases which contain one verb and one not verb word. In this way, our algorithm generates patterns which recognize domain specific event descriptions. Our empirically-derived hypothesis is that most of the specific events will be effects of the disasters and recovery operations, as well as deployment of emergency-response teams.

Experiments and Evaluation

We applied our grammar learning algorithm on a news corpus from the disaster domain. In particular, we used the set of not annotated news articles about floods which happened in different parts of the world in the beginning of 2016, another set of new articles about the tropical storms Erika (August 2016), Joaquin and Patricia (in 2015), as well as the quake which have hit the coasts of Sumatra in March 2016. The overall size of this corpus was 381 articles. In order to evaluate our algorithm, we used a small test corpus of 21 articles about the 2016 earthquake in Ecuador. This test corpus contains 198 annotated micro-events. The grammar which we have created has extracted 321 event-description phrases. In our evaluation we considered correct each event phrase which overlaps by one or more words with a phrase from the annotated corpus.

Precision and Recall were found to be 42% and 66% respectively. Considering that our algorithm is unsupervised, these numbers are encouraging, but clearly the results can be improved further. In particular, with some minor efforts we can boost the precision significantly by performing a manual inspection on the learned results and leaving only the relevant clusters and cluster pairs.

Our algorithm has detected phrases which express killings and injuries of people, damage and collapse of buildings, deployment of emergency crew, as well as recovery and rescue operations.

Table 1. A news article about the earthquake in Ecuador and the extracted phrases

News article	Rescuers start to arrive after Ecuador quake 1666 "QUITO, Ecuador The Latest on the earthquake in Ecuador. (all times local): 7:45 a.m. Authorities in Ecuador are mobilizing resources and help is getting to the ground after a long night of fear and uncertainty caused by a magnitude-7.8 earthquake that killed at least 77 people. Vice President Jorge Glas is overseeing efforts until President makes an emergency return from a visit to Rome. Glas arrived Sunday morning in Manta along the coast along with dozens of rescuers. The city's airport is badly damaged, but is receiving relief flights. National airline TAME has already organized two humanitarian airlifts with members of the Red Cross and police reinforcements. More than a dozen roads have been closed due to damage from the earthquake, making it harder for rescuers to reach where they are needed most. The Transportation Ministry says that the hardest hit was Manabi province, near the epicentre. Eight major roads there were either closed or partially collapsed from landslides or strong movements of the earth.
Extracted phrases (correct ones are marked with *)	**rescuers start, *start to arrive after Ecuador quake, uncertainty caused, caused by a magnitude-7.8 earthquake, *earthquake that killed, *killed at least 77 people, *President makes an emergency return, emergency return from a visit, National airline TAME has already organized, *dozen roads have been closed, *closed due to damage from the earthquake needed most, Ministry says that the hardest hit, *roads there were either closed or partially collapsed, *closed or partially collapsed from landslides*

Here are some other examples of relevant phrases which our algorithm managed to detect in the test corpus: *dozen roads have been closed, building above the shop collapsed, collapsed structures are a hotel, family were among those killed, people had been reported as missing, difficult for emergency workers to reach the towns* *hardest hit*, *continued to pick at rubble looking for survivors and victims*, *caused numerous victims and great damage*, *closed due to damage from the earthquake*, *roads have been closed*, *people have died*, *closed or partially collapsed from the landslides*. Most of the erroneously extracted event phrases were about the fact that the quake occurred, announcements and incomplete phrases about disaster effects. In our final evaluation we did not consider such phrases as correct, although they are not completely wrong either. Such phrases can be used to pinpoint to disaster effects which will be mentioned afterwards.

TOWARDS CREATING A CORPUS OF DISASTER-RELATED MICRO EVENTS

We created a news corpus annotated for micro-events which resulting from natural disasters. First, we have collected from the Web news about major earthquakes, wild fires, landslides, and floods. Then, we annotated the mentions of each micro-event belonging to one of the following event types: damage on people, damage and abandoning of infrastructures, vehicles, and services, such as transport, electricity, water and gas and more. The corpus is available at http://nlp.kiv.zcu.cz/projects/dime.

We did not enumerate the types of micro events, since creation of a micro-event taxonomy is beyond the scope of this paper, however we envisage to do that in our future work. Instead, we created a gold annotation for each type of natural disaster - flood, earthquake, forest fire and landslide and we used this gold standard as a reference, when we annotated the other articles. The final version of the corpus is envisaged to encompass around 200 articles and the version we have produced currently has around 70 articles.

SUPERVISED LEARNING OF EVENT DETECTION GRAMMARS

Although the unsupervised grammar learning algorithm, described in the previous subsection generated a substantial number of interesting patterns, the main problem is that these patterns are not labeled with the event types they detect. That is, the system which uses such patterns cannot distinguish between deaths, building damages, road closures, airport closures, and other disaster effects, although it can pinpoint to the text which describes those events. In order to perform more topically focused extraction of event patterns we carried out experiments with another semi-automatic learning algorithm.

We applied the algorithm described in (Tanev and Zavarella, 2013) in order to learn patterns consisting of a combination of words about a resource or entity and event description phrases, like in the following sample rule for Building Damage events:

```
event_rule :> ( leftPattern & [CLASS:"Damage"]
       participatingEntity & [CLASS:"Building", SURFACE:#surf] )
-> event & [CLASS:"Damage", PARTICIPANT:#surf ]
& PossibleSlotFor(Damage,Building)
```

where `PossibleSlotFor(X,Y)` is a Boolean operator checking whether the `participatingEntity` class `Y` is one the possible classes which may fill the slots of a pattern of class `X`. The method is provided with a conceptual specification of the target domain (a specification of domain entities and the event relations they participate in), a few initial words for those classes and an unannotated tweet corpus. It continues by expanding entity classes, learning entity modifiers and event patterns, which can then be encoded in simple finite-state rules.
In this way we have learned lexical patterns in English, Italian and Spanish for the following disaster-related events:

- Building damage
- Service interruption (transport services, hospitals, schools, and others)
- Emergency crew deployment
- Shortage and distribution of food, water, shelters, medical resources or fuel

Subsequently, we used the learned patterns to filter a stream of Twitter status messages, retrieved from the Twitter public Streaming API. We have conducted preliminary accuracy estimation on a set of the 20 retweeted messages in English on 25 November 2016 and we have found that 80% of the detected events are correct. This evaluation is based on a quite small test set and it lacks generality, since most of the events belonged to the classes "Building damage" and "Emergency crew deployment", nevertheless it shows that the algorithm is potentially useful for gathering information about ongoing developments after disasters hit. We deploy such patterns in the Twitter application we present below.

DETECTING EYEWITNESS TWITTER STATUS MESSAGES

We wanted to evaluate how accurately one could automatically detect the relatively tiny fraction of eyewitness social media content communicated during disasters and separate it from the large amount of messages that talk largely about the same event, by deploying statistical Machine Learning text classifiers, trained on Twitter data taken from previous disaster events.

Features

In order to deal with the multilingual content communicated through social media one has to rely on shallow language features, as many largely spoken languages in the world are under-resourced with respect to language processing tools, such as POS taggers, parsers, etc. For this reason, compared to other previous works (e.g. Pekar et al., 2016) we experimented with a minimal set of language features that could be mostly produced using language-independent methods, and we test our approach on English and Italian.

Lexical:

uni-grams: we extract a ranked list of the *n* most relevant unigrams features (*n* is around 3100 and 1900 for English and Italian, respectively) from the corpus of all tweets for a target language (regardless of the label), by using a simple TF/IDF scoring, removing features containing Twitter metadata reserved characters. We apply them with no prior score-based weighting. The method applies a stopword list as the only language-specific resource and is thus easily portable across languages.

n-grams: analogously we extract a ranked list of the most relevant n-gram phrases, with no prior restriction on the length of the phrase.

number of unigrams: as some evidence was found by (Power et al. 2015) that first-hand emergency reports tend to be comparatively shorter, we apply a numeric feature for the token-based length of the tweet.

Stylistic:

Personal: similarly to (Pekar et al., 2016) we create a Boolean feature encoding whether the tweet text contains terms from a small lexicon of deictic expressions, including first-person pronouns/adjectives and adverbials (e.g. I, our, here, etc.). The assumption here is that an eyewitness account will more likely be written from a first-person perspective. We hand coded these small lexicons for both English and Italian.

All-caps: as word capitalization is used in social media jargons as an interjection marker to attract the reader's attention, we assume a first-hand account from a disaster affected person will more likely be all-caps. We create a Boolean feature indicating if the tweet contains only capital letter words.

Twitter Metadata:

hashtags: we add to the vector space a feature for each hashtag found in the dataset (e.g. *#Yolanda*), and then assign it 1 if it occurs in an instance tweet and 0 otherwise.

containsHashTags: this encodes the fact that an instance tweet contains at all hashtags or not.

user mentions: analogously, we create a Boolean feature for each user mention (e.g. *@denvernews*) found in the dataset.

containsMention: this encodes the fact that a instance tweet contains user mentions at all.

urls: adding URLs in a tweet is a form of linking previously published content and is thus potentially a distinguishing feature of non-first-hand situation reports. However, URLs may link multimedia content originating from the tweet's author himself, as different for example from linking news media or government sites. In order to account for URLs qualitatively, we add features for all URLs collected from the dataset.

containsURLs: encodes the fact that a tweet contains URLs at all or not.

RetweetCount: a numerical feature for the number of times a message has been retweeted. We assume here that novel situational updates from the affected people should gain comparatively more attention and being more re-posted.

fromMobileDevice: we check the Twitter message client application in order to determine whether it was posted from a mobile device or not.

IsReply: we assume that eyewitness reports are not likely to be posted as replies to previous messages.

Semantic:

Category Definitions: We use Boolean features each encoding the matching of one of 13 rule-based category definitions relevant to the disaster domain. Namely, we use the disaster-related event patterns learned by the algorithm described in the previous Section, and deploy them in a more lenient mode by simply combining predicate and entity lexicons by Boolean operators, with proximity restrictions. Example category features are "Infrastructure Damage", "Service Interruption", "Shelter Needed", etc.

The rationale here is that first-hand reports during a crisis, as distinct for example from mere sympathy expressions, will likely be classified in one or more of the micro-event topics the affected people are mostly concerned about. Moreover, as the micro-events and the corresponding lexical resources are rather general across disaster instances and disaster types, this feature set should boost classifier accuracy generalization across disasters. However, the list of modelled micro-event topics is not exhaustive, therefore we do not expect this to largely boost Recall.

Experimental setup and Evaluation

We worked with data from the labeled part of the CrisisLexT26 corpus (Olteanu et al., 2015). This corpus comprises over 24k multilingual tweets produced during 26 diverse mass emergency events (including floods, wildfires, bombings, etc.) from 2012-2013 collected through Twitter Sample API and annotated for 3 semantic dimensions: Informativeness, Information Type, and Information Source. This latter attribute, our target class in this experiment, in CrisisLexT26 ranged over the nominal values Eyewitness, Government, NGO, Business, Traditional/Internet Media, Outsiders; as we want a binary classification task, we merged the latter labels into one, so we are left with only "Eyewitness" and "Non-Eyewitness" in the dataset. Because we used the data to extract lexical features, we had to further filter by language, which was done by using an in-house language detection module, based on continuously updated language specific frequency tables (Steinberger et al., 2013). Moreover, as we need to query Twitter APIs for retrieving meta-data features and some of the messages or accounts from the dataset are not accessible or existing anymore, we ended up with 2 datasets of 10342 tweets (950 positive instances) and 465 tweets (52 positives) for English and Italian, respectively. After some preliminary tests we measured that the performance of learning algorithms was rather poor for such skewed datasets, therefore we balanced them (50/50%) by randomly under-sampling the negative instances before training the classifiers, using Weka Spread Subsample algorithm implementation (Hall et al., 2009).

We evaluated to what extent classifiers trained on our feature set were able to generalize to unseen test sets, both intra- and across event types. To this purpose, we compared the performance of a standard 10-fold cross validation, where the feature distribution in the test and training data is likely to be similar (we label this evaluation mode CrossEv), with a "hold-out" scenario, where we train the system on data from a subset of the events and test it on a separate subset of events, either of the same event type (SplitIntr) or a different one (SplitAcross). The two latter experiments emulate better a real-world scenario, where eyewitness messages from a new unseen disaster need to be detected by a classifier that has been trained on previous events.

Table 2 reports Precision, Recall and F1-measure for 3 different classifiers we experimented with: Naïve Bayes, Support Vector Machine and Random Forest, as implemented in Weka (Hall et al., 2009). Experiments were performed both in English and Italian language, for the 3 scenarios illustrated (CrossEv, SplitIntr, SplitAcross).

There is an evident performance drop for the SplitIntr and SplitAcross scenarios, particularly for the Precision, which confirms the well-known issue with domain adaptation for tweet classification tasks (see Li et al., 2015). Figures for Italian are somehow difficult to interpret, as performance unexpectedly grows from SplitIntr through SplitAcross across all three classifiers, which may be partially due to limited dataset size.

Table 2: Performance of 3 eyewitness report classifiers on the same feature set, for 10-fold cross-evaluation, intra-type hold-out and cross-type hold-out evaluation.

		NaïveBayes			SVM			RandomForest		
		P	R	F1	P	R	F1	P	R	F1
EN	CrossEv	0.700	0.843	0.765	0.798	0.748	0.772	0.808	0.774	**0.790**
	SplitIntr	0.148	0.413	0.218	0.215	0.370	**0.272**	0.162	0.348	0.221
	SplitAcross	0.116	0.683	**0.198**	0.116	0.341	0.173	0.117	0.293	0.167
IT	CrossEv	0.639	0.750	**0.690**	0.567	0.654	0.607	0.573	0.827	0.677
	SplitIntr	0.098	0.889	**0.177**	0.093	1.000	0.171	0.088	1.000	0.162
	SplitAcross	0.239	0.981	0.385	0.240	1.000	**0.387**	0.188	1.000	0.317

Overall, results significantly outperform the previous works on the same dataset. For example for English we nearly double F1 for the best classifier from (Pekar et al., 2016) in CrossEv scenario, and raise the best F1 from around 7 up to 17 and up to 27 for the SplitIntr and SplitAcross scenarios, respectively, while we still make use of comparatively fewer and less deep features. However, direct comparison is not possible as they were not balancing the dataset. As we explained, the lexical features can be easily extracted from unlabeled data: this suggests that tackling the domain adaptation issue may be achievable in our approach by simply integrating unlabeled instances belonging to the new target event into the dataset.

Moreover, results for Italian and English are roughly comparable, which provides evidence that our choice of using only shallow linguistic features makes the method quite scalable across languages.

Overall, all features showed low to medium correlation with target labels (≤.3 and ≤.4 for English and Italian, respectively). This is probably due to the fact that the whole corpus is heterogeneous and distribution over disaster types and disaster instances is unbalanced, which is confirmed by some top ranking but highly specific hashtags (e.g. #Modena, #yycflood). Nonetheless, some of the *Personal* features (*my*, *io*, *mia*) consistently ranked among the highest across the two languages, together with some topic related unigrams (*crash*, *flood*, *dead*, *terremoto*, *vittime*). Interestingly, some perception and cognitive state verb unigrams (*sentito*, *svegli*) were highly correlated with the positive class in Italian, which suggests that a new dedicated semantic feature class may be added. Finally, the *containsURLs* feature turned out to be unexpectedly correlated with positive class for both languages.

BUILDING A TWITTER APPLICATION FOR MONITORING DISASTER IMPACT

We deployed the methods illustrated so far in a simple on-line application based on the Twitter platform. Disastrobot (https://twitter.com/DisastroBot) is a Twitter channel that dynamically tracks target disaster events worldwide by filtering, tagging and re-posting Twitter status messages, therefore serving as a social media content hub for situation monitoring and impact assessment. The system is multilingual and currently comprises resources for English, Italian and Spanish.

The channel maintains a list of 5 target disaster events (currently only Quakes, Floods and Hurricanes), which is dynamically updated by processing an RSS feed from the GDACS portal (http://www.gdacs.org/) and applying heuristic functions of the event Severity, Affected Population and duration of the monitoring. For each target event, a pre-filtering is automatically created by submitting to the Twitter public Streaming API a query comprising:

1. A number of geographical bounding boxes heuristically computed from the disaster geo-coordinates and severity;
2. A set of domain-specific terms/hashtags capturing the type of the event (e.g. *#quake, inundación*)

The tweets continuously collected are then processed by the event detection grammars described earlier. Each tweet matching one of the 13 event types is then retweeted on the channel timeline, labeled with a corresponding hashtag (e.g. *#DSTRServiceInterruption*, *#DSTRFoodShortage*, etc.). By using hashtags we add an event meta-information layer to the textual content and allow users to visualize situational updates for selected event types (by just clicking on the type hashtag). Additionally, topic-classified tweets are processed by a trained classifier for eyewitness report detection, and a corresponding *#DSTREye* label is possibly added.

Fig.1 below shows sample tweets published on Disastrobot on 25th of November 2016.

Figure 1. Snapshots from the Disastrobot Twitter channel timeline.

CONCLUSIONS

We presented and evaluated a novel unsupervised algorithm for event detection and we have applied it on news articles, in order to detect descriptions of the effects of disasters. The algorithm accuracy can be improved further, but even without manual supervision, it succeeds in detecting a significant amount of micro-events. Integrating some supervision through bootstrapping learning iterations can be also used to continuously enhance the grammar model.

We also presented a Twitter application which is based on a weakly-supervised algorithm for learning of event-detection rules. This application detects disaster-related micro-events, reported on Twitter in three different languages. Compared to previous approaches to tweet topic classification our method does not require extended annotated data: however, we are planning to use the relatively accurate output of our learned rules to generate event-annotated training data for statistical classifiers, in view of extending the current system recall. In the same direction, we intend to experiment with applying our unsupervised algorithm to Social Media data and with assigning topic labels to the non-categorized output patterns: this could be done by computing similarity with the patterns extracted by the second algorithm.

For both event and eyewitness report detection, we are currently exploring methods for adapting the feature space of statistical classifiers to the contexts of target disasters, by dynamically integrating unannotated training data from the incoming event streams. This should mitigate the domain adaption performance drop and is still a missing component in view of making the system usable in operational scenarios.

Finally, we aim to generalize the methods in order to process content across different social media platforms.

ACKNOWLEDGMENTS

The work was partly supported by Project MediaGist, EU's FP7 People Programme (Marie Curie Action), no. 63078.

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The Impact of Social Media for Emergency Services: A Case Study with the Fire Department Frankfurt

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ABSTRACT

The use of social media is not only part of everyday life but also of crises and emergencies. Many studies focus on the concrete use of social media during a specific emergency, but the prevalence of social media, data access and published research studies allows the examination in a broader and more integrated manner. This work-in-progress paper presents the results of a case study with the Fire Department Frankfurt, which is one of the biggest and most modern fire departments in Germany. The findings relate to social media technologies, organizational structure and roles, information validation, staff skills and resources, and the importance of volunteer communities. In the next step, the results will be integrated into the frame of a comparative case study with the overall aim of examining the impact of social media on how emergency services respond and react in an emergency.

Keywords

Social media, emergency services, facilitators and obstacles, comparative case studies.

INTRODUCTION

For almost 15 years, social media has been part of everyday life, also appearing in critical situations (Reuter & Kaufhold, 2017). Already after the 9/11 attacks in 2001, citizens created wikis to collect information about missing people (Palen & Liu, 2007), and FEMA and the Red Cross used web-based technologies to inform the public and to provide status report internally and externally (Harrald et al., 2002). Many studies focus on the concrete use of social media during a specific emergency, such as the 2011 London riots (Denef et al., 2013), the 2012 hurricane Sandy (Hughes et al., 2014) or the 2013 European floods (Reuter et al., 2015). These studies demonstrate specific ways in which social media responded to various crises. However, the high prevalence of social media, data access via social media API's and published research studies allows the application of methods for examining social media during emergencies in a broader and more integrated manner. Amongst these methods are comparative case studies (Yin, 2013), representative surveys and systematic literature reviews (Brocke et al., 2015).

This work-in-progress paper presents the results of a case study with the Fire Department Frankfurt, which, in the next step, will be integrated into the frame of a comparative case study with the overall aim of examining the impact of social media on how emergency services respond and react in an emergency. After a concise literature review (section 2), the paper presents the key findings of a pre-study whose results informed the scoping of the comparative case study (section 3). Thereafter, the design and results of the case study with the Fire Department Frankfurt are presented (section 4). Finally, the conclusion outlines the key findings of the case study (section 5).

FOUNDATIONS

Social media use in emergencies has become a very big research field, sometimes summarized under the term *crisis informatics*. Coined by Hagar (2007) and later elaborated by Palen et al. (2009), it "views emergency response as an expanded social system where information is disseminated within and between official and public channels and entities". Today, crisis informatics "is a multidisciplinary field combining computing and social science knowledge of disasters; its central tenet is that people use personal information and communication technology to respond to disaster in creative ways to cope with uncertainty" (Palen & Anderson, 2016).

In the last years, plenty of case studies on emergency services' perception, enablers, barriers and actual use of social media were published. On the one hand, there is a positive attitude towards the use of social media and, for instance, the majority of US authorities already use social media as they value its suitability for information dissemination (San et al., 2013). This includes warnings, advice and guidance on how to cope with or prevent emergencies or disasters, hints and advice on how to behave during an emergency, coordination of the help of volunteers, summary information after an emergency, and coordination of clean-up activities (Reuter et al., 2016). Furthermore, a study on 2012 hurricane Sandy reported that communication differed between fire and police departments and across media types (Hughes et al., 2014).

However, on the other hand, a study observed that authorities use social media comparably less to receive messages (Reuter et al., 2016). The perceived unreliability of such information (Mendoza et al., 2010), organizational prohibitions and a lack of formal policies to guide the use of social media (Plotnick et al., 2015) are significant obstacles in exploring opportunities of integrating citizen-generated content (Mendoza et al., 2010). Hughes and Palen (2014) complement the challenges of verification, liability, credibility, information overload, and allocation of resources. Thus, several applications and methods were developed and examined to integrate citizen-generated content and support authorities in processing social media content. For example, Moi et al. (2015) propose a system to process and analyze social media data, transforming the high volume of noisy data into a low volume of rich and high-quality content that is useful to emergency personnel. However, further research is required to foster good practice of social media use and related technology, and to overcome the barriers and challenges from the perspective of emergency services and across cultural boundaries.

PRE-STUDY: COMPARATIVE CASE STUDY ON FLOOD SCENARIOS

Methodology

The overall aims of the pre-study, which focused on the theme of 'flooding', were researching a) the impact of social media on how emergency services (ES) respond and react in an emergency and b) how citizens use social media in an emergency, how they use it to interact with each other and others, including ES, and what impact this has on them (Spielhofer et al., 1016). The pre-study is based on a 'multiple case study' approach which allows for exploration of the impact of social media in emergency situations through the use of a 'replication strategy', in which successive case examples are selected to explore and confirm or disprove the patterns identified in the initial case examples (Yin, 2013).

In a preliminary analysis (Junge et al., 2014), five themes were identified, which formed the specific research questions and study objectives, which are a) patterns of social media usage, b) social media roles, c) quality of information, d) scale of social media information and e) organizational and professional factors. The case study methodology was based on the three interconnected stages of scoping, data collection, analysis and integration. The findings from the different flood case studies (2013 Elbe in Germany, 2015 Tbilisi in Georgia, 2014 Ljubljana in Slovenia, 2010 Wroclaw in Poland, 2014 Western Norway floods, and 2013/14 Wiltshire in UK) were summarized in standardized case study reports and finally analyzed comparatively using an item analysis procedure. The results serve as foundation of the methodology and topics of this case study.

Key Findings

Use of social media in flooding emergencies

The level and purposes of social media use and the roles of different actors involved varied considerably from case to case (Hughes et al., 2014). In the German case (Kaufhold & Reuter, 2016), Twitter was used as a platform for status updates and Facebook pages were mostly used by volunteer communities to provide an overview of the situation, to coordinate response efforts and to filter the vast information supply. In Tbilisi, social media was used during and after the flood to post pictures and videos, to inform other people on the scale of the disaster, to contact friends, to find information on the safety of specific areas and road access, to trace needs, and to offer help. In Ljubljana, the emergency services used social media to send out warnings and information during the flood, mainly through Facebook and Twitter.

Information quality and the impact of 'rumors'

In the Tbilisi case, initially, social media provided an immediate picture of what was happening, in contrast to conventional media, which were much slower to respond. However, inaccurate information was a major problem; the rapid and wide distribution of rumors caused greater panic and fear. Yet, a 'self-correcting' mechanism was identified, where other citizens used social media mainly to highlight false and misleading information. In the Wroclaw case, the evidence suggests that citizens were motivated by a desire to provide specific and useful information regarding the flood situation and the information disseminated through social media was generally of high quality. However, from the perspective of the emergency services, issues were still raised regarding the veracity and credibility of the information circulated through citizen to citizen communication.

Scale and impact of social media data for emergency management

The key impacts of the use of social media during and after the analyzed flooding emergencies can be summarized as (1) more efficient and effective coordination of information by volunteers, often in real-time, on events related to the flooding; (2) more effective and fast dissemination/broadcasting of timely information on what was happening more widely by emergency services and volunteers; (3) providing emotional support and solidarity, particularly among citizens and (4) demonstrating the potential of social media in improving the effectiveness of emergency services' responses, and, in some cases, promoting changes in organizational systems and processes.

Obstacles to the use of social media

The case study analysis highlighted four main sets of obstacles to the use of social media in emergencies: (1) lack of organizational structures and procedures in place – on the whole the structures and networks already developed in emergency services to support the use of social media were limited; (2) lack of resources, staff and skills – for example respondents in Western Norway emergency services reported that they had virtually no personnel trained in using social media, and a corresponding lack of tools and expertise; (3) lack of systems and procedures to deal with information overload; and (4) verification of information – services were often not confident about the veracity of the information circulated through social media.

CASE STUDY: SOCIAL MEDIA TECHNOLOGIES OF THE FIRE DEPARTMENT FRANKFURT

Background and Methodology

Since 1874, Frankfurt am Main has a professional fire department, the Fire Department Frankfurt (FDF), that is one of the biggest and most modern professional fire departments in Germany. Employing approximately 1,000 people, this fire department is also one of the biggest public offices in the city administration of Frankfurt am Main (W1). With a population of 732,000, Frankfurt is both the biggest city in the German federal state of Hessen and the fifth-largest city in Germany (W2). Twelve fire and rescue stations, organized in four groups, are spread throughout the urban area. Additionally, further 900 active members work in 28 volunteer fire departments to supplement with the tasks of fire protection, rescue service and technical danger prevention. In Frankfurt, the fire department coordinates every non-police hazard prevention unit.

The aim of this case study focuses on researching the impact of social media on how emergency services respond and react in an emergency. Based on the results of the pre-study, the objectives of this study comprise emergency services' a) tools, platforms or technologies, b) organizational structures and facilitators, c) social media users and uses, d) information validation, e) staff skills and resources, and f) moderation of volunteer communities. It is intended to contribute to another 'multiple case study' round of successive case examples to explore and confirm or disprove the patterns identified in the initial case examples (Yin, 2013) and, if all or most of the cases provide similar results, to develop a preliminary theory that describes the phenomena (Eisenhardt, 1989).

By recommendation of a consortium member of the EmerGent project (http://fp7-emergent.eu/), we approached the FDF by performing a short key informant interview (K1) with the head of the press and public relations department to get a general overview of the organization, their social media use and available documents of interest. Thereafter, we conducted two in-depth interviews (I1, I2) with one of their press spokesmen who is responsible for social media use. For each of the study's objectives, 2-4 related questions were integrated into the interviews (see appendix). Furthermore, source material of social media presences (Facebook, Instagram, YouTube, Twitter), their website (W1), Wikipedia for basic information about Frankfurt (W2) and FDF (W3), and a video presentation (V1, https://www.youtube.com/watch?v=ieU6TVCjAcU), which addresses the social media strategy of FDF including a Q&A session, were analyzed. Interviews were audio-recorded and transcribed for further analysis. In our subsequent analysis we employed "open" coding (Strauss & Corbin, 1998), i.e. gathering data into approximate categories to reflect the issues raised by respondents based on repeated readings of the data and its organization into "similar" statements. The identified themes were then processed according to the structure of the following results section to enable comparability with upcoming case studies. While the analysis was conducted in German, the quotes selected for this article were translated into English by the authors.

Findings

Social Media Tools, Platforms or Technologies: Usage, Strengths and Weaknesses

The opening of the European Central Bank (ECB) in 2015 in Frankfurt was a significant event that made the FDF realize the need to take the use of social media for communicating with citizens more seriously (I1, 14:05). During that event, multicultural protesters not only attacked police but also relief forces such as the fire services and with the help of social media communication, the FDF could reduce the attacks on relief forces. They now see social media as a central part of their daily routine: "We consider the use of social media to be essential." Therefore, they differentiate between the real and the virtual situation of an operation. The real situation includes, for example, actions undertaken by emergency personnel in the context of an emergency. The virtual situation depends on context and public interest. For operational communication, *Twitter* is used as a central key tool, not only to provide current information about ongoing operations, but also to warn citizens in dangerous contexts such as fire (K1). In March 2015 and a few days after the ECB riots, its use was promoted with a 24-hour campaign using the hashtag *#24h112* where FDF posted tweets about their daily routine: everyday life, operations and training units (V1, 12:10).

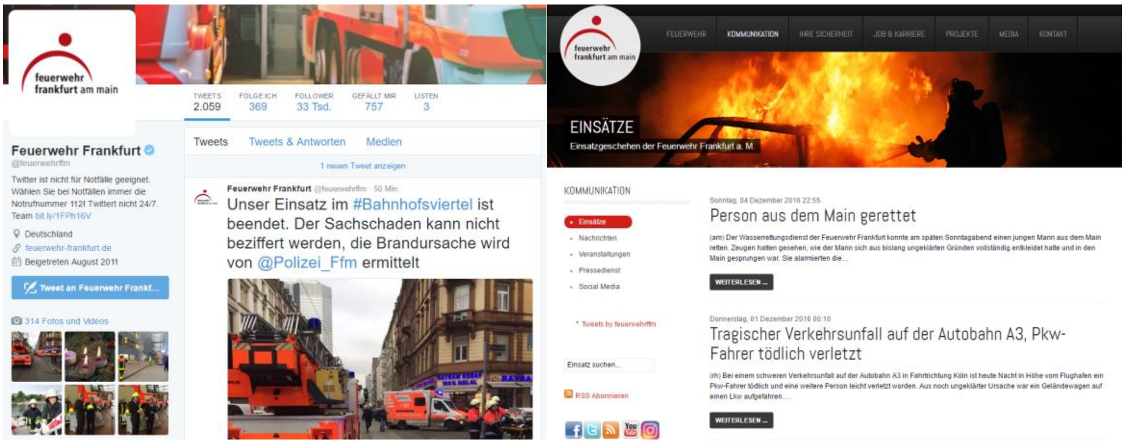

Figure 1. Twitter account and website of the Fire Department Frankfurt

However, for traditional organizational communication (I1, 03:15), for instance, to recruit talented young employees, FDF uses *Facebook*, *Instagram* and *YouTube*. Especially Facebook was intended to represent FDF as an employer and in 2015, for instance, Markus Röck reported the receipt of about 800 applications for 40 open positions (V1, 08:00). Contrary to the Feuerwehr München (Fire Service Munich), they deliberately decided to not put operation reports to Facebook, because they saw conflict potential between the reports, which may contain information about deaths, and the like button mechanism, and therefore anticipated a high effort of moderation. Instead, FDF directs all communication to their lead channel Twitter (I2, 09:20). Instagram and YouTube, then again, depict the different units of the fire department, their areas of responsibility, interviews and practical exercises. The same applies to Facebook, where additional pictures provide insight into different exercises. The FDF maintains a **website** with the goal to inform people and to facilitate communication. In Twitter, links to operation reports and in Facebook, security advices of the website are often embedded into messages.

Table 1. Social Platforms of Feuerwehr Frankfurt (4th of January 2017)

	Facebook	Instagram	Twitter	YouTube	Website
Start	February 2013	October 2016	August 2011	August 2012	December 2011
Reach	61808 sub.	3238 sub.	39979 followers	2169 sub.	442482 visitors
Publication	542 posts	39 pictures	2106 tweets	26 videos	215 news
Purposes	Publicity, recruitment	Publicity, recruitment	Operational communication	Publicity, recruitment	Publicity, recruitment, safety information

For both monitoring and analysis of social media content, FDF uses *TweetDeck*, a dashboard application for the management of Twitter accounts, due to its real-time capability in terms of monitoring keywords and hashtags and free access. However, it is not used 24/7 because emergency calls are assumed as staring points for monitoring in relevant situations. Since the volume of social media data does not allow monitoring of unfiltered data, FDF uses different search strategies to find essential and relevant information with TweetDeck, e.g. reducing the number of sources (e.g. monitoring important media agencies only), filtering for tweets with a certain propagation (e.g. tweets that were retweeted at least 10-20 times) or using keywords with query operators if the user is familiar with it and the emergency allows to spend time on refining the search term (I2, 03:40). Finally, for internal direct communication, the FDF uses messengers such as *Telegram* that are encrypted and meet the industry standards in terms of messenger communication (I1, 26:36).

Several events such as the opening of the ECB in Frankfurt in March 2015 highlighted the main strengths of social media (I1, 14:05): "These networks provide the possibility to influence and control real-life behavior." Another positive effect was shown in the context of refugee aid in September 2015 when social media calls were used to mobilize spontaneous volunteers and delegate many suitable tasks accordingly (I1, 14:05). Moreover, communication and coordination of the public via social media is often much faster than traditional channels, supporting rapid information delivery and response. However, this also means that people that are dissatisfied with the work of FDF or disappointed can also react faster and distribute their opinion on the internet. Hence, it can be said that the increased speed of communication puts the FDF under pressure. Furthermore, the FDF does not have sufficient personnel resources and thus has problems to invest the time needed (I1, 20:39).

Table 2. Pros and Cons of Social Media Use

Pros	Cons
Influence and control real-life behavior	Limited personnel and time resources
Rapid delivery of and response to information	Pressure due to fast information response
Reach, e.g. providing information for journalists and press	
Personnel recruitment	
Public image maintenance	
Operational communication (esp. Twitter)	

In terms of the social media tools, FDF values the real-time capabilities for monitoring keywords and hashtags, the integrated filtering options and the free access of TweetDeck. They also analyzed commercial solutions such as Brandwatch, a social media monitoring tool, which are too expensive and whose target groups are not organizations such as fire departments (I1, 06:50). However, TweetDeck only supports Twitter, and citizens may publish relevant information, including media such as pictures or videos, on different social media. The "optimal" social media tool should provide a good overall usability, capabilities to pre-structure actions and content, the flexibility to adapt it to the current emergency, support for all relevant social media, and possibilities to capture the mood of citizens. He concludes that current systems are too expensive, not operational enough and more suited for medium- or long-term observations but not for emergencies (I2, 06:28).

Organizational Structure and Facilitators: Integration, Enablers, Barriers and Resistance towards Social Media

Social Media is a central part of FDF's organizational structure and integrated into their everyday practice and operational plans. Three departments are subordinated to the head of office: 1) Press and public relations, 2) staff council and equal opportunities officer, 3) hazard prevention and 4) infrastructure. The access to and the use of organizational social media accounts are restricted to **press spokesmen** working for the press and public relations department (I1, 12:49). The respective staff is trained appropriately to use social media as a standard procedure in emergencies. As press spokesmen are connected technically 24/7 via laptops, mobile phones and tablets, they can immediately react to emergencies, regardless of whether the person is at home or at the deployment site (I1, 06:50). Another factor is that almost everybody within the organization uses social media privately and thus the whole workforce of 1900 people operates as a "search algorithm" and contributes to monitoring activities (I1, 11:16). A further factor is that, although the fire department is a strongly hierarchical organization, they established an organizational structure which enables press spokesmen to disseminate tweets quickly without administrative barriers that could hinder the timely dissemination of relevant information (V1, 30:50). Thus, a progressive organizational culture is required to enable a successful integration of social media.

However, the limited budget and personnel resources do not allow to communicate over and monitor social media full-time, because press spokesmen also must fulfill regular fire department duties and interact with traditional media (V1, 26:00). A press spokesman indicated that some employees may not like social media or feel overrun by the technology (I1, 20:39). However, due to the organization's hierarchical structure this is not an issue because the employees follow instructions from the top management, which demands the use of social media (I1, 33:42). Therefore, the employees comply with the requirements. It is worthwhile to mention that FDF is a big fire department with a focus on communication. They hired a former Twitter employee to teach the employees in using social media for their communication. Furthermore, a press spokesman indicates that they are creating documents to formalize existing problems, strategies to overcome them, and related tasks, measures and tools (I1, 35:10). However, these documents are more like a comprehensive checklist currently, but an integrated concept, which allows to implement an effective and quick use of social media, is still missing. Some remaining questions are: What is operatively relevant information in social media? How can we aggregate and integrate the information to improve the picture of the emergency and to influence decisions? What are the potentials of social media in (daily) medium and large-scale emergencies?

Social Media Users and Uses: Types of Staff, Information and Roles

Only press spokesman have access to organizational social media accounts and therefore can use social media over official channels. However, employees, especially from the voluntary fire departments, contribute using their private social media accounts by actively sending potentially relevant information or passively being monitored (I1, 11:16). FDF explicitly publishes operational information on Twitter not only to provide reliable information for the general population, journalists and the press, but also to increase the reach with the presence of the channel in traditional media. Moreover, volunteers may perform basic tasks during emergencies, but due to insufficient personnel resources, it is not appropriate to use social media „to keep the citizens onboard" and to organize groups of volunteers: "Spontaneous volunteers are employed spontaneously and otherwise they should become part of a volunteer fire department."

FDF is especially interested in the public mood of citizens (I2, 06:28) and potential rumors or misinformation (I1, 03:15) to prevent negative influence from the virtual realm on the real emergency. Furthermore, it is important to identify misinterpretations of the situation to counter a potential loss of trust (I2, 11:26). From the analysis of the November 2015 Paris attacks and 2016 Munich shooting, FDF sees the necessity to establish a *lead communication* which means adopting the moderating role in the current emergency and providing information to citizens in sufficient quantity and speed. To establish the lead in such situations, the population's trust is required, but it is perceived as an opportunity to control and counter rumors or misinformation (I1, 14:05).

Information Validation: Credibility of Information, Procedures of Validation and Technological Support

Although TweetDeck is used for monitoring social media, FDF does not use a special tool with information validation components (K1). In a research project, they furthermore examine an information quality approach for filtering social media content based on the 1) geolocation of the user, 2) credibility of the source, 3) relevance of the source, 4) credibility of information and 5) relevance of information (I2, 15:36). Using this approach, each component is assessed with a score and the person responsible for emergency communication can define a threshold to filter information: "At the beginning of an emergency, I just want to see information with a relatively high score in terms of credibility and relevance. With an increasing number of staff involved, however, the threshold could be reduced to get a more comprehensive picture of the incoming information" (I2, 15:36). Furthermore, tools must support the fast identification of low quality posts, misinformation and rumors to implement a fast information policy, which allows to counter these (I1, 14:05) and to establish a lead communication.

Staff Skills and Resources

A general rule of FDF requires that personnel must perform communication tasks in the daily routine to be prepared for communication during emergencies (I2, 28:06). Some of the relevant skills identified by FDF to find, interpret and use social media are a) an understanding of different social media networks, corresponding tools and their characteristics, b) skills to keep up with the development of technology, its new variations and fields of deployment, and c) socio-psychological strategies on how to counter irrational behavior in social networks. From the perspective of resources, multiple positions are required that explicitly deal with the topic of social media communication to ensure a good social media performance continuously as well as to develop and improve best practices and guidelines (I1, 20:39).

Although a former employee of Twitter is currently responsible for increasing the employees' skills, it is very difficult to expand the employees' expertise due to the rapid development of technology, new variations and fields of deployment over the recent years, making it hard to exploit the maximum potential of social media yet (I1, 20:39). Furthermore, the necessary personnel resources are limited. Although there is a motivated team dealing with social media, administrating daily work is very time-consuming so that "it is very difficult to invest the time necessary to deal with social media conceptually" (I1, 20:39). According to a press spokesman, the inertia and the salary structure of the public service prevents an effective and efficient competence development. Therefore, FDF also considers the deployment of Virtual Operation Support Teams (VOST) and, furthermore, guidelines for the use of social media in emergencies that are valid across organizations would help the (inter-)organizational overcoming of emergencies. A press spokesman proposes the establishment of a central institution which "analyzes emergencies, reveals problems, develops solution strategies and recommends tactical measures in terms of a catalogue of measures which is available for all federal states, municipalities and districts" (I1, 20:39).

Moderating Communities: Importance, Engagement, Support and Cooperation

During the 2013 European floods and even more during the September 2015 refugee aid, FDF realized the value of spontaneous volunteers in performing a variety of required "non-hazardous" tasks. In the latter case, volunteers performed some special tasks (e.g. interpreting/translation), but in tendency more general tasks that require no specialization (e.g., supervision) (I2, 31:16). A press spokesman emphasizes that social technologies enable volunteers to organize much faster than previously, which constitutes a novelty (I1, 23:50). Furthermore, the engagement with communities depends on the scale of the emergency, which can be an isolated event or affect a large area. In the latter case, the federalism of Germany constitutes an issue to create comprehensive interaction concepts: Because fire departments are municipal organizations and, in this case, as soon as the emergency exceeds the borders of Frankfurt, the handling of outside areas comes under the responsibility of other organizations which may implement other interaction concepts (I1, 20:39).

Social media communities are handled as autonomous units. During refugee aid, for example, FDF established a tentative operations center together with the federal police, the German Railways and selected contact persons of volunteer communities. For improved engagement, FDF considers the deployment of VOST: "Because we have volunteer fire departments all over the town with honorary employees that work in different environments of their regular jobs, we just need to search those with basic skills in communication and the respective technology to build up displaced teams" (I1, 26:36). These displaced teams then could be activated as VOST and provided with self-coordination tasks via the internet during large-scale emergencies (I2, 31:16). Moreover, social media, traditional media and press can provide guidance, increase the public perception of volunteer communities and therefore help maintaining their motivation over an extended period (I2, 33:06). The presented VOST approach could be applied to create stronger connections and trust with citizens and citizen communities through mutual support in overcoming the emergency (I1, 26:36).

CONCLUSION AND OUTLOOK

This paper presented, based on a literature review and pre-study, the results of a case study with the Fire Department Frankfurt (FDF). The FDF uses Twitter as lead channel for operational communication while complete operation reports are available at (and linked via Twitter to) the official website. Facebook, Instagram and YouTube are primarily used for public image maintenance and employee recruitment, but occasionally for the dissemination of safety advices by linking the respective content from their website. Besides the above-mentioned purposes, the possible influence and control of real-life behavior, the reach (e.g. in combination with journalists, press and traditional media) and the integration of spontaneous volunteers are recognized as strengths of social media. Contrary, the limited personnel and time resources and the pressure to act due to fast information response were mentioned as weaknesses of social media. TweetDeck is not used for social media monitoring 24/7 but on demand during emergencies. Commercial solutions such as Brandwatch were analyzed by FDF but are too expensive and, as they are not optimized for emergency services, do not fulfill the requirements of FDF. However, the need for an information quality application tailored for emergency services became apparent and they are already putting research effort into this issue.

This case study provides insights for practitioners on the successful organizational integration of social media and still existing challenges. The most important aspect is that social media is an integrated part of the organizational culture and structure of FDF. Press spokesmen exclusively manage social media communication, using the lead channel of Twitter, directly without administrative barriers that could hinder the timely dissemination of relevant information. The basic guidelines on social media use, the coaching of a former Twitter employee and the hierarchical structure ensure the adaption of social media. The FDF proposes the establishment of a central institution, which "analyzes emergencies, reveals problems, develops solution strategies and recommends tactical measures in terms of a catalogue of measures which is available for all federal states, municipalities and districts". These could help overcome inter-organizational work, especially if an emergency overlaps different areas of responsibility, and improve the integration of spontaneous volunteers. Spontaneous volunteers and social media communities are valued as important stakeholders in overcoming emergencies or large-scale disasters, but due to limited resources, it is impossible to moderate them all. However, the FDF thinks about implementing VOST teams based especially on the (personal) networks of honorary employees of the volunteer fire departments, but additional research is required concerning the optimal implementation and evaluation of VOST.

The study has some limitations. Firstly, besides the analyzed documents, interviews with one press spokesmen constitute the primary source of information. However, social media use at the FDF is restricted to press spokesmen who are a small group following the same social media guidelines, and the interviews with managerial staff provided insight into the underlying decision-making processes. Secondly, the study only provides limited insight into an ongoing comparative case study; the need for additional information and interviews, including other organizational roles, with the FDF may become apparent during preliminary analysis of the other planned case studies. After conducting the individual cases, similar to the pre-study, the case of FDF will be integrated and further analyzed in the frame of the comparative case study to confirm or disprove the patterns identified in the initial case examples (Yin, 2013).

ACKNOWLEDGEMENTS

The research project EmerGent was funded by a grant of the European Union (FP7 No. 608352). We would like to thank all members of our project and participants of the study.

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APPENDIX: INTERVIEW GUIDELINE

Theme 1: Social media tools, platforms and technologies

1. How does your organisation access/analyse social media currently?
2. What specific tools do you use?
3. When are they used?
4. Who uses them?
5. For what purposes are they used?

Theme 2: Organisational structures and facilitators

1. In what ways and to what extent is the use and analysis of social media integrated into your organizational structures and systems?
2. To what extent does this facilitate or hinder the use of information gained from social media?
3. What would you say are the main barriers to the widespread and systematic use of social media in your organisation?
4. How do you think these barriers could be eliminated or reduced?
5. What specific things would you say could facilitate the use of social media by your organisation in general?

Theme 3: Social media users and uses

1. Which types of staff in your emergency services are most likely to look for information on social media?
2. What types of information are you most interested in finding out from social media?
3. What roles have citizens played in emergencies in your area in the past?
4. What kinds of social media citizen roles would be most useful for your organisation?

Theme 4: Information validation

1. Have you experienced any problems with the level and quality of social media data generated in emergencies in the past?
2. What procedures and tools did you use to validate information efficiently and effectively?

Theme 5: Emergency service staff skills and resources

1. What skills are required to help emergency services such as yours to find, interpret and make use of social media data?

2. Would you say that staff in your organisation in general have these skills and resources?
3. What guidance or training do you think would be most useful to help emergencies services like your own to use social information efficiently and effectively?

Theme 6: Moderating citizen communities

1. Do you use citizen communities in any way to help you access or analyse social media data before, during or after an emergency?
2. In what ways and to what extent do you engage with these communities?
3. What else could be done to support social media volunteer communities in emergencies to help them become more efficient and effective?
4. What else could you do before an emergency to make stronger links with such communities?

Mining Multimodal Information on Social Media for Increased Situational Awareness

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ABSTRACT

Social media platforms have become a source of high volume, real-time information describing significant events in a timely fashion. In this paper we describe a system for the real-time extraction of information from text and image content in Twitter messages and combine the spatio-temporal metadata of the messages to filter the data stream for emergency events and visualize the output on an interactive map. Twitter messages for a geographic region are monitored for flooding events by analysing the text content and images posted. Events detected are compared with a ground truth to see if information in social media correlates with actual events. We propose an Intrusion Index as part of this prototype to facilitate ethical harvesting of data. A map layer is created by the prototype system that visualises the analysis and filtered Twitter messages by geolocation.

Keywords

Spatio-temporal, Social media analysis, Multimodal analysis, Geolocation.

INTRODUCTION

In this work we present a system that combines the spatio-temporal metadata of Twitter messages with an analysis of the content of the messages, which includes text and images. An evaluation is presented that motivates the system to be used in an emergency or disaster scenario, and will allow emergency managers to increase their understanding of events as reported on social media. The system aims to mine and extract latent information in social media text, analysing the content of the messages, performing image recognition, and creating a spatial data layer that can be used to visualise the results on a web map. Combining the spatial and temporal data of social media with the content of the messages in this way can reveal potentially sensitive information. These privacy concerns must be addressed in any system that performs collection, processing, analysis, and visualisation of social media data.

This paper describes a system that integrates content analysis methods for social media messages and image analysis with the spatial and temporal data inherent in each message to extract meaningful information about ongoing events. It also includes a tool that allows a user to observe data privacy. We look at disaster and emergency management as the domain of application. An output and demonstration of the system is presented where messages and conversations related to flooding events and storm landings in Ireland are detected by looking at geolocated messages in these regions. For Ireland this is during the period of December 2015 to January 2016.

The system uses the spatio-temporal metadata of the Twitter messages to track the unfolding of an event on social media as discussed by members of the public. A method and implementation of monitoring the potential *intrusiveness* of this system is also described that uses natural language processing to allow a user of the system to engage in ethical data harvesting and analysis as part of work conducted by the authors previously (Kelly &

Ahmad, 2014, 2015). Visualisation of the analysis and system output is also illustrated by creating a map layer that can be incorporated into any geographical information system or web map. We show that by utilising the spatial and temporal aspects of social media data and analysis of the text and image content of the messages, effective and timely information can be extracted to increase situational awareness and can be summarised and visualised to aid decision making for an emergency manager.

RELATED WORK

Information published on social media platforms has been known to contain valuable information that is timely, often geographically tagged, and descriptive of ongoing events, all of which is information that can increase awareness of a situation (Vieweg, Hughes, Starbird, & Palen, 2010). Situational awareness is an important concept for crisis and emergency management where informed decision making is vital for efficient operation and management of a crisis event (Yin, Lampert, Cameron, Robinson, & Power, 2012). The benefits and use of social media for organisational purposes and as a new channel of information has been demonstrated early on since the emergence of microblogging (Sutton, Palen, & Shklovski, 2008). Methods and systems have been developed to do topic and trend detection, prediction, and forecasting (Althoff, Borth, Hees, & Dengel, 2013; Jin, Gallagher, Cao, Luo, & Han, 2010). Visualisation and methods of displaying this information have also been investigated in order to increase situational awareness for users (Mathioudakis & Koudas, 2010). Detecting events has been an integral part of these systems, where burst detection in the volume of messages has been a typical approach (Dou, Wang, Skau, Ribarsky, & Zhou, 2012; Li, Lei, Khadiwala, & Chang, 2012; Mathioudakis & Koudas, 2010; Robinson, Power, & Cameron, 2013). Machine learning techniques have also been employed to filter the deluge of information published on microblogging platforms with reliable levels of accuracy (Imran, Elbassuoni, Castillo, Diaz, & Meier, 2013).

Spatio-temporal models have been investigated in a number of studies to find the location of a targeted event such as earthquakes (Sakaki, Okazaki, & Matsuo, 2010; Yin et al., 2012), flooding events and fires (Vieweg et al., 2010), conflicts and political disasters (Dou et al., 2012; Ritter, Etzioni, & Clark, 2012; Robinson et al., 2013), with some systems attempting to automatically detect events (Li et al., 2012). The importance of publication time of these data has been highlighted for use in prediction (Li et al., 2012).

Some systems, such as *TwiCal* (Ritter et al., 2012) and *Tweet4act* (Chowdhury, Imran, Asghar, Amer-Yahia, & Castillo, 2013), have attempted to analyse the content of the messages also. It has been shown that by using natural language processing techniques on social media messages that contain a particular topic useful information can be extracted for a particular domain (Aiello et al., 2013). This example is encouraging and indicates that social media contains useful and relevant information. Key difficulties in this research area include verifying information, extending to other media types, going from situational awareness to decision support, and data privacy issues (Adam, Shafiq, & Staffin, 2012; Imran, Castillo, Diaz, & Vieweg, 2015).

SYSTEM OVERVIEW AND METHODS

The following section discusses the system with conceptual outline of shown in Figure 1. The Slandail Social Media Monitor provides a framework for performing domain-specific multimodal analyses on geographically bounded social media data streams. To begin analysis a geographical region on a map is specified through the GUI and domain filters are set which specify which semantic dictionaries to use. The system connects to Twitter via Twitter's Streaming API to pull in all messages from the geolocation specified by the user of the system. The demonstration described here uses the Twitter API but can connect to the APIs of other social media platforms (Facebook, Instagram) using the same architecture.

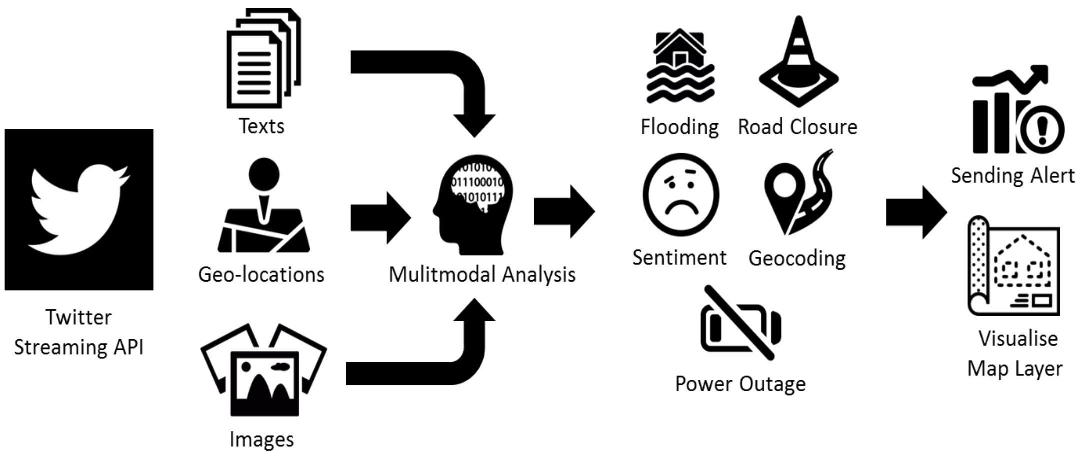

Figure 1. Domain-specific multimodal analyse of a social media stream to identify messages with images and text content related to emergency scenarios with geolocated information to produce an alert from the filtered social media stream and a map layer to visualise results

When the system is running, the message stream is pulled from the API and pre-processing is performed to extract feature, which are then passed to a classifier to see if they are relevant for emergency management. To analyse the text content of each message Stanford's CoreNLP package is used to perform tokenisation and part-of-speech tagging of the raw text. A Twitter specific part-of-speech tagging model is used in place of the general language model included in the CoreNLP package (Derczynski, Ritter, Clark, & Bontcheva, 2013). Technical details of the text analytics system, and the Slandail Social Media Monitor which has been developed in Java, have been presented in Zhang et al (Zhang, Kelly, & Ahmad, 2016). The text features were generated using the frequency occurrence of the disaster terms in the social media messages (Spyropoulou, 2016). Images contained in the messages are passed to an image recognition model that has been trained specifically to identify classes of images that are relevant for emergency scenarios and has been developed, tested, and published as part of the Slandail project (Jing, Scotney, Coleman, & McGinnity, 2016; Jing, Scotney, Coleman, McGinnity, et al., 2016). Processing messages in this way allows the text and image content to be analysed and to determine whether relevant information about an emergency or disaster event is present in the message.

The system can perform a real-time analysis of a social media stream by using an asynchronous processing pipeline. This allows collected messages to be processed in separate threads and improves error handling by ensuring no single message disrupts the analysis pipeline (Zhang et al., 2016).

Processed messages are then filtered for relevancy where only messages related to an emergency event are kept. The filtering of the text is performed by identifying domain terms defined in a set of domain dictionaries where only messages with these domain terms will be kept for subsequent analysis. A semantic dictionary, in the context of this paper, simply refers to a mapping from linguistic patterns to their semantic categories. The linguistic patterns in such dictionaries are expressed in TokensRegex (Chang & Manning, 2014) a regular expression implementation that matches token sequences rather than character sequences. Defining linguistic patterns at the token level enables the matching of complex patterns. The domain dictionaries referred to here include a categorised list of terms for emergency situations or concepts, such a flood or hurricane, which have been compiled into a term base and published as part of the output of the Slandail project (Spyropoulou, 2016) and available on the Slandail website[1].

The result of analysing each message can be presented in the front end of the system in two ways. First, by aggregating the frequency of the occurrence of disaster-related concepts into a time series and visualising them as a dynamic time series plot that can be adjusted by time. The second way is in the main interface, which includes the base map, and each geolocated messages is indicated as a point on this map. An example of the front end of the social media monitor is shown in Figure 2.

The location of each message collected and analysed is used to produce a map layer to visualise where messages were published or are referring to, this can be seen in Figure 2 where OpenStreetMap is used as the base map. If the geographic coordinates are included in the metadata of the tweet then this is used as the exact location of the message (red marker). In many cases this location data is not included, in this case the location attributed to the

[1] www.slandail.eu

user profile can be used. This location is more frequently included in the metadata of the tweets. This can be combined and cross-referenced with references to locations in the text (green marker). The coordinates of places names detected are found by using Google Maps Geocoding API[2]. As the query formulated for collecting tweets using the API is set to only include tweets that are geolocated in the area of interest, for the purpose of demonstration, we assume that all tweets returned are relevant. The front end shows how the frequency of relevant terms and topics being discussed in a location on social media has evolved over time as several time series graphs. Each message with a location is represented as a point on the base map and has a clickable dialogue that allows the message, its accompanying metadata and any images posted to be viewed. A breakdown of all relevant messages for the region is also shown (right most dialogue window Figure 2). This dialogue window allows a user to quickly scan through up-to-date messages that have been posted and contain either an image or message content related to one of several categories in the Slandail disaster terminology, or one of the classes of the image classifier. The particular example shown in Figure 2 includes messages containing information about floods, power outages, and road damage.

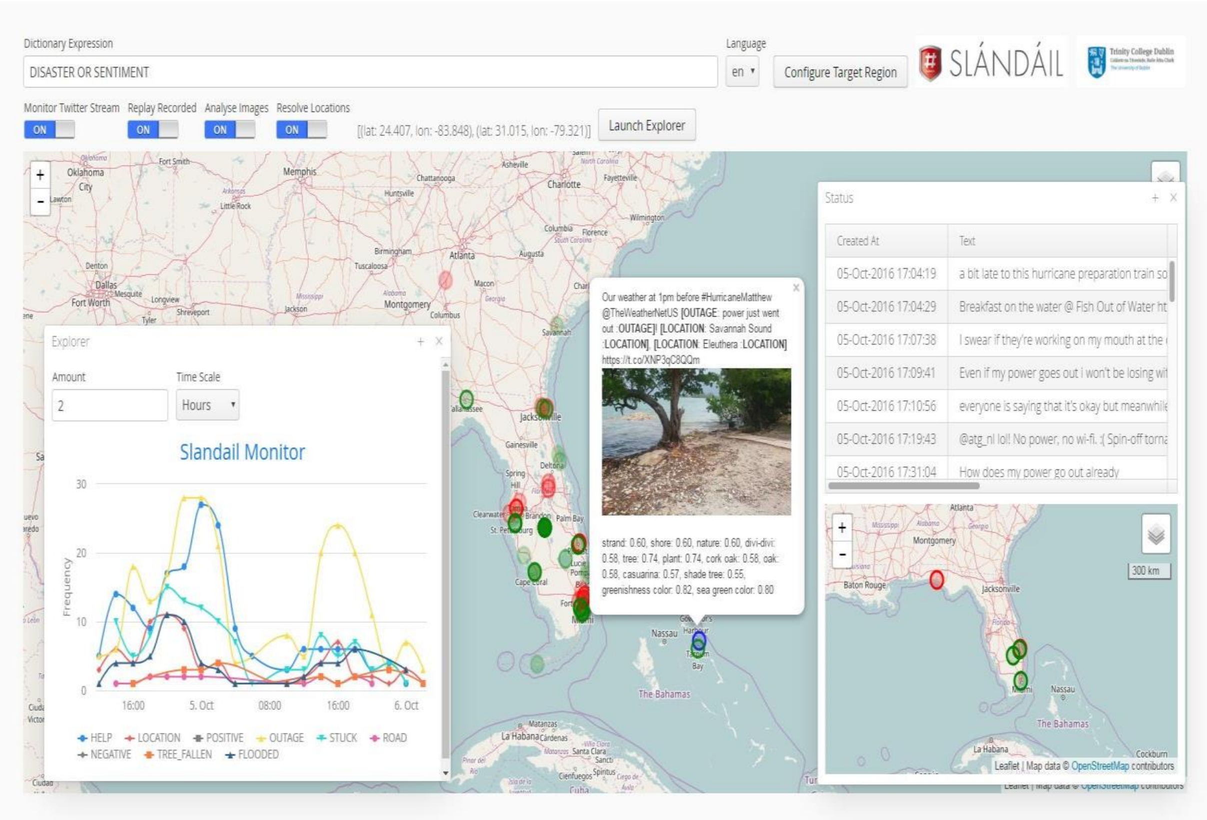

Figure 2. Front end of the social media monitor system showing filtered and relevant geolocated messages and images for the location under investigation, the frequency at which these messages have occurred, and a drill down menu to examine the messages and accompanying metadata.

A novel framework has been proposed and published as part of the Slandail project that allows the integration of image and text data from social media messages to improve image recognition in the event of a natural disaster being reported on social media. An implementation and trained model has been incorporated into the social media monitor presented here to facilitate the real-time recognition of images. For image feature extraction, all images are first resized to a standard size to have maximum height of 480. Colour images are converted to greyscale in order to calculate SIFT or SURF features based on the key interest points detected (Jing, Coleman, Bryan, & McGinnity, 2015; Jing, Scotney, Coleman, McGinnity, et al., 2016). For SIFT or SURF features, the key interest points are first detected and then the feature descriptors are calculated. The final image feature used for classification is the histogram of visual words based on the Bag-of-Words model (Niebles, Wang, & Fei-Fei, 2008).

Image features are extracted using the Bag-of-Words model and has been evaluated using two different flooding image corpora, one from the US Federal Emergency Management Agency's media library and another from

[2] https://developers.google.com/maps/documentation/geocoding

publicly available Facebook pages (Jing, Scotney, Coleman, & McGinnity, 2016; Jing, Scotney, Coleman, McGinnity, et al., 2016). The work presented by Jing et al (Jing, Scotney, Coleman, McGinnity, et al., 2016) utilises the proposed SIPF algorithm (Jing et al., 2015) and highlights the feasibility of real-time image analytics and incorporates the method into the monitor presented here for the recognition of images related to an emergency event.

Image and text features are fused during the learning process, where the model is trained on sample data. In one implementation of the image and text recognition system contained in the Slandail monitoring system, the image and text features are combined on the feature level. Images and their accompanying text captions or text descriptions are turned into features using the approach described previously in this section and are then concatenated into a single feature vector. It is assumed that these features are related semantically. The text accompanying an image often describes or elaborates on the image. A corpus was built containing images and accompanying text captions for classes related to emergency and disaster topics. Training a classifier with these feature vectors allows both text and image content related to the disaster or emergency classes to be detected. The sample corpus has been made available online and linked the Slandail Social Media Monitor[3].

Classification is performed by using a Support Vector Machine (SVM) and trained on the fused features with a test set consisting of fused features also (Jing, Scotney, Coleman, McGinnity, et al., 2016). The main approach presented shows an increase in the performance of image recognition by incorporating the text features extracted from the content of the accompanying messages. The mean average precision of the classifier is seen to improve in every instance where text and image features are used together to classify a social media message as opposed to just the image alone and demonstrates an advantage in recognition and reducing the burden of interpretation for an emergency manager (Jing, Scotney, Coleman, & McGinnity, 2016; Jing, Scotney, Coleman, McGinnity, et al., 2016).

Privacy preserving measures are incorporated into the system to help monitor the level of sensitive information being detected. To do this the presence of entities such as individual names, institutions, places and events that occur in the messages are detected using named entity recognition. The frequency occurrence of these messages in time is monitored and an *intrusion index* is formed to log whether the system is detecting a high degree of potentially sensitive information and was first presented in (Kelly & Ahmad, 2014, 2015). The system uses the Stanford Name Entity Recogniser (NER) for detecting entities (Toutanova, Klein, Manning, & Singer, 2003). The frequency of these entities, specifically person and place names, is recorded for each time period to compute a time series of entity occurrence. By locating and keeping a record of entities that have occurred in text, emergency managers and users of the system can measure the level of intrusion and personally identifiable information being collected. This may help emergency managers using the Slandail Social Media Monitor to be aware of the potential intrusiveness of the system and to help in deciding whether to anonymise stored data or delete data collected after the period of an emergency. An example of the output of the intrusion index includes a time series log of entities detected in messages (Figure 3).

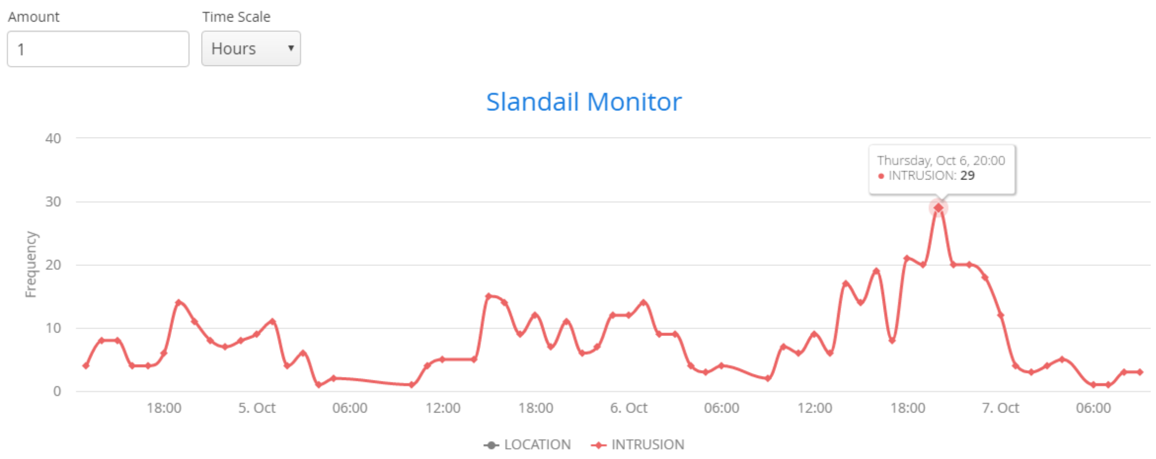

Figure 3. Slandail Social Media Monitor's visualisation of the *Intrusion Index* displaying the volume of entities.

Figure 3 shows a screen shot of the dialogue window from the Slandail Social Media Monitor indicating the frequency of entities occurring in the corpus of messages. This data is shown as a graph in the monitor front end

[3] https://sites.google.com/a/tcd.ie/slaindail-image/

but also stored as a log file. Typically an increase in message volume correlates with an increase in the number of entities detected. Normalising the series by accounting for the total number of words versus the occurrence of entities can give a better indication of periods where a higher than normal number of sensitives messages have been detected. The individual messages are flagged as containing named entities and have a higher potential of containing sensitive information. This can be logged and stored as meta-data with any messages that may be kept. End users and emergency managers within the Slandail project expressed interest in being able to recount the historical data that they may have made decisions on and to review the efficacy and justifications for these decisions at a later date. For the Slandail Social Media Monitor an online version of the system has been deployed on a standalone web server which allows the system to operate independently of a local machine and can be accessed from both mobile and standard web browsers for demonstration purposes[4].

DEMONSTRATION

To demonstrate the system's ability to filter a stream of social media data we use a corpus of Twitter messages retrieved using the public Twitter API for the period between the 20th of December 2015 to the 2nd of January 2016 (Table 1). We constructed the query for the API so as to only return messages that were geolocated in Ireland. This introduces a spatial dimension to the data as we are aware that the corpus is relevant to the location of Ireland. This time period was chosen as a number of flooding events and storms had occurred in Ireland during this time. The system was used to detect flooding events, or mentions of such on social media, during this period based on the content of the messages being posted in Ireland. Of the messages collected during this period we find that just over 6% of the messages randomly sample from the geolocation of Ireland were in reference to the storms landing (Table 1). There is little difference in negative or positive sentiment expressed during this time. An inspection of the disaster and emergency related messages shows people mainly discussing factual events or expressing information and opinions about the adverse weather conditions.

Table 1. Shows the number of Twitter messages with terms from the dictionary categories and the total number of terms in the text collection for each category. The sample includes Twitter messages geolocated in Ireland for the period from 20/12/2015 to 02/01/2016.

Category	Messages	Terms
Total	7944	161,885
Negative	2542	3569
Positive	2682	3183
Disaster &Emergency	484	500

The temporal component of each message together with their known location is used to identify conversations about flooding events on Twitter in Ireland during the sample period. By analysing the content of Twitter messages for an area, the topics of conversation can be compared to real world events happening on the ground. This type of information is very beneficial for informing emergency managers about ongoing events.

[4] Access to the online system can be granted by request to the authors

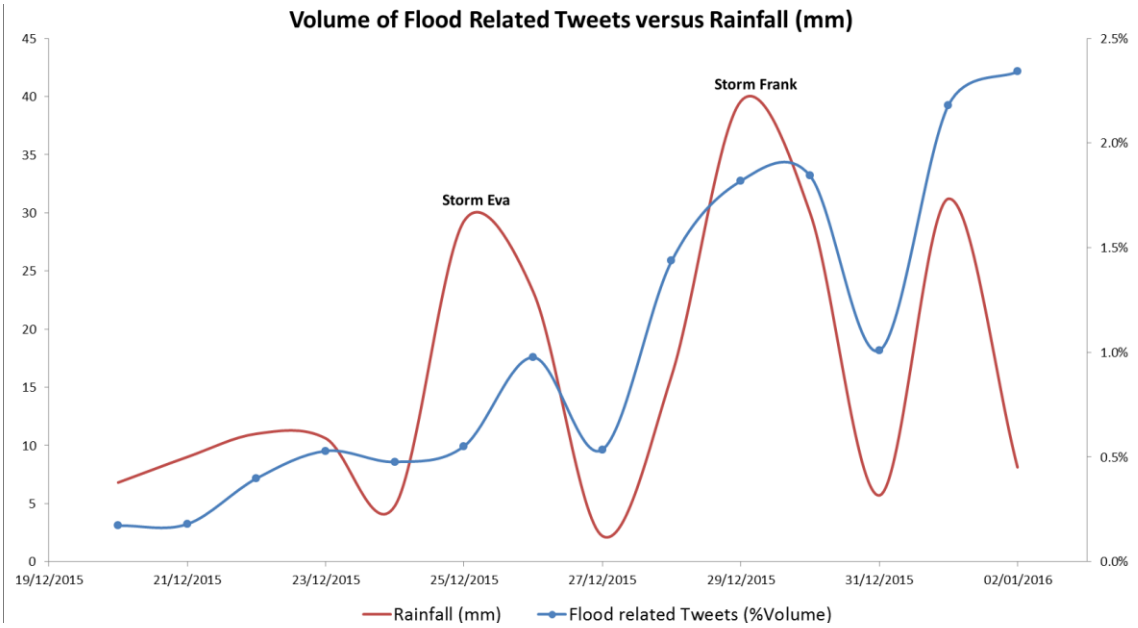

Figure 4. Shows the normalised volume of tweets tagged as begin geolocated in Ireland and identified as being relevant for flood related topics as compared to rainfall data during the landfall of several storms in Cork, Ireland between December 2015 and January 2016.

For the event detection, a ground truth was referenced based on average daily rainfall data for the region of Ireland. Meteorological data from the Irish national weather authority MetEireann[5] was used to create a time series of rainfall data for the sample period of December 2015 and January 2016. This period included the time of landfall of several major storms in Ireland. The rainfall increased at the time of landfall of these storms. The objective was to determine if the Slandail Social Media Monitor would detect an increase in the conversation about flooding and adverse weather conditions in Ireland on Twitter during this period.

From Figure 4 an increase in the volume of tweets in Ireland about flood related topics is seen and by observation looks to be correlated with the landfall of major storms and the increase in rainfall. The correlation of the two series during this period is seen to be 54%. This demonstrates the system's ability to detect conversations regarding real world events on Twitter by including the spatio-temporal characteristics of the data.

LIMITATIONS AND FUTURE WORK

A limitation of the system has been in user engagement and incorporating the output of the geolocated social media analysis into existing decision making processes for emergency managers. The objective of the Slandail Social Media Monitor has been to analyse and aggregated relevant social media messages containing content that would be of interest to an emergency manager and present it in a way that is familiar to them. This has included filtering the social media stream and presenting it as geolocated information on a map. Future and on-going work has included aggregating the output of the social media analysis in the Slandail monitor with data and variables that an emergency manager might typically use such as location of potential hazards, population density of an area, or proximity to bodies of water that may flood. A model has been proposed in forthcoming work by the authors that relies on fuzzy aggregation theory to incorporate the output of the social media analysis with additional data that emergency managers can use in their decision making process. This model weights the severity of information measured at a particular time and uses a type of weighted average to produce a single output that can be used to inform and support decision making (Mesiarová-Zemánková, Kelly, & Ahmad, 2017). Another concern for emergency managers and the Slandail monitor is how to handle rumours and false information. In this case, methods are being investigated to weight the reliability of a message based on heuristics about the user and their credibility (Gupta & Kumaraguru, 2012).

A powerful application of this system is to visualise analysis by location. Those who are first to encounter these areas are often locals of the area of people using the roads or amenities in the flooded areas. These people may also take to social media to announce problem areas and flood roads as a matter of interest or to inform authorities and the general public. To this end the system identifies messages and images that are relevant to the

[5] http://www.met.ie/climate/daily-data.asp

topic of flooding and combined with the geolocation of the messages can visualise this data to see potential areas of interest for an emergency responder. An example of this output for the Florida storms in the U.S has been shown in Figure 2. Here a larger scale study is currently being investigated where over a million tweets consisting of messages and images have been compiled during the landfall of Hurricane Mathew in October 2016. This study which is part of our future work looks at the time serial reporting of events and categorizes messages into the phases of emergency including preparedness and recovery in order to better understand the dynamics of how disasters are reported and discussed on social media.

CONCLUSION

This work has described the implementation of a system that combines the spatio-temporal aspects of social media data with the content of messages and images posted to create insights into unfolding emergency related events as reported on social media. The system has used content analysis and image analytics to filter messages and identify content related to emergency and disaster situations. It has been demonstrated that a correlation exists with a corpus of data which tracks the topic of conversation on Twitter in Ireland about flooding and the landfall of two major storms. Given the large volume of messages published by individuals on Twitter, it is clear that by combining the spatio-temporal attributes of messages with the content and images posted, sensitive information about people and their locations can be identified. A method has been integrated into the system that facilitates the ethical harvesting of data in the form of an intrusion index. This allows a user of the system to be more informed about the potential intrusiveness of the system. Lastly, the output of the system includes the creation of a map layer and time series data that allows the results and analysis of the system to be visualised. These visualisations are incorporated into a front end that displays the geolocation of the messages and system output on an interactive map with dynamic graphs in separate dialogue windows. The system described here can be used to better inform decision making for a user, and to better organise and filter relevant content from social media. The demonstration of the system shows an application in the area of emergency and disaster management where receiving timely, relevant information about ongoing events and data privacy can be addressed.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European community’s Seventh Framework Programme under grant agreement No.607691 (SLANDAIL). The materials presented and views expressed here are the responsibility of the author(s) only. The EU Commission takes no responsibility for any use made of the information set out.

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International Conference on Availability, Reliability, and Security

Rumors detection on Social Media during Crisis Management

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ABSTRACT

Social Media monitoring has become a major issue in crisis and emergencies management. Indeed, social media may ease the sharing of information between citizens and Public Safety Organizations, but it also enables the rapid spreading of inaccurate information. As information is now provided and shared by anyone to anyone, information credibility is a major issue. We propose an approach to detect rumor in social media. This paper describes our work on semantic graph based information fusion, enhanced with uncertainty management capabilities. The uncertainty management capability enables managing the different level of credibility of actors of an emergency (different PSO officers and citizens). Functions for information synthesis, conflicting information detection and information evaluation were developed and test during experimentation campaigns. The synthesis and conflicting information detection functionalities are very welcome by end-users. However, the uncertainty management is a combinatorial approach which remains a limitation for use with large amount of information.

Keywords

Semantic information fusion, Uncertainty management, Ontology, Graph matching, conflict detection, rumors detection

INTRODUCTION

Emergencies and crisis throughout the World prompted new attention to the role new mobile technologies and social media platforms play in such situations. This role takes action from the situation assessment phase, with new sources of information about the ongoing (potentially remote) situation, to the dispatch of response efforts. As information is now provided by anyone, information credibility is a major issue. People may spread inadequate, incomplete or inaccurate information. As the propagation of rumors is speed up and widened, emergency and crisis response officers (PSO - Public Safety Organizations) must take this new issue into account.

In this paper, we propose an approach for rumor detection within a social media monitoring context. Figure 1 depicts the four steps of the overall process described hereafter.

Event Report Typing. In a first step, short messages are received and processed in order to identify the semantic type of the event they relate. Each short message is transformed into a unitary typed event report.

Event Report Fusion. Within the second step, the compatible unitary reports are fused into a bigger and richer fused event report. The compatibility is assessed thanks to domain dependent heuristics and similarity measures called “strategies”

Conflict Detection. Intimately linked to the previous step, the conflict detection among event reports triggers alerts when some typed event report is not compatible with any previously processed event. This means that a new event has been reported. This new event may either be a rumor or a real event.

Information Evaluation. When a new event is detected, it is evaluated in order to verify its credibility. This enables supporting PSO in the detection of potential rumors. PSO will then manage these rumors within the crisis development.

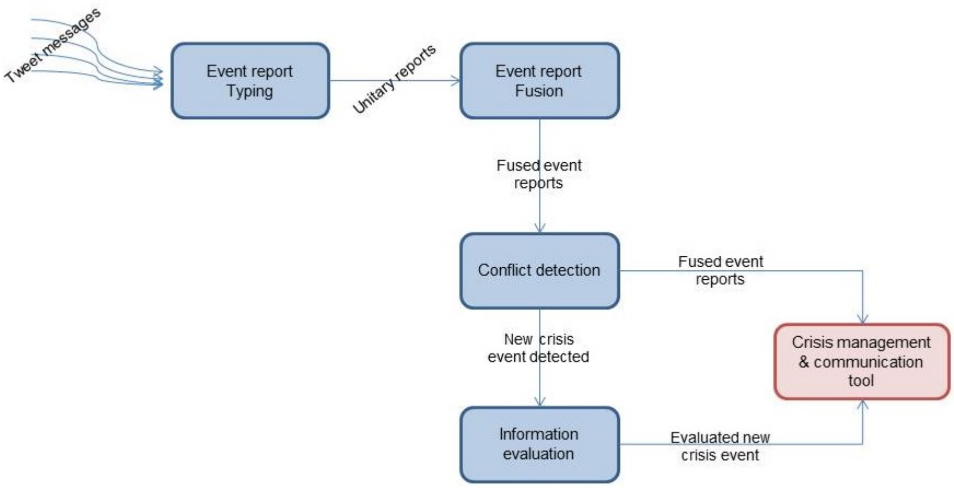

Figure 1. Overall rumor detection process

The first section of this paper presents related work. We then describe the theoretical approach for semantic fusion. The different steps of the rumor detection process rely on this theoretical approach. Each step is implemented, based on part of the theory. The third section details how this theoretical approach is used for rumor detection in social media. After that, we describe some experimentations of our system in which end-users tested the usefulness and usability of the functions. We finally conclude and present directions for future work.

RELATED WORK

The detection of rumors on social media shows an increasing interest in the research community. (Seo et al. 2012) present an approach for the identification of the source of a rumor on Twitter. This approach is then extended so to determine whether information is a rumor or not. The underlying idea is that rumors have few sources while real information is emitted by numerous sources. Therefore, when suspicious information is detected, one search for its sources which enables the categorization of the information either as a rumor or as a real information. This work differs from our objectives in the way that in our Social Media monitoring support issue within crisis management, the PSO actors want to detect and stifle the rumors rapidly, before it can be spread out. Therefore, we cannot wait for the information to be propagated on the social media, but must act as soon as it appears.

In (Sun et al. 2013), the authors detect events in the micro-blogs by detecting keywords and event verbs. These keywords and verbs are collected a priori in an event based verbs dataset.

The rumors detected in (Sun et al. 2013) are of a very particular type. They are so called text-picture unmatched rumors. In other words, they detect micro-blogs were the images illustrating an information are not really related to this information. The images either related to older information or are built.

The work described in (Takako Hashimoto 2011) is very close to our work as it aims at detecting a rumor as soon as it is first mentioned on the social media. Micro-blogs are analyzed in order to build a network of information containing all the information contained in the different micro-blogs. Whenever the structure of this network has a very big change, the authors suspect that a rumor has been spread. The information causing the big structural change is verified with so called "certified" information sources.

SEMANTIC INFORMATION FUSION

Graph based Information Representation

Graph based representations appear to be naturally well adapted to soft data. Our approach relies on the use of bipartite graphs, more specifically a subset of the conceptual graphs ((Sowa 1984), (Chein and Mugnier 2008)) to represent soft data and knowledge. The conceptual graphs formalism is a model that encompasses a basic ontology (called *vocabulary*), graph structures and operations on the graphs. The vocabulary defines the different types of concepts and relations that exist in the modeled application domain, while the graphs provide a representation of the observations which are provided by the information sources.

Basic **conceptual graphs** are bipartite graphs containing concept and relation nodes. Figure 2 gives an example of a conceptual graph. The rectangular boxes represent concept nodes and the ovals represent relation nodes.

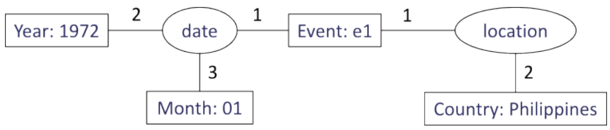

Figure 2. Example of a conceptual graph

The term **concept** is used to refer to a concept node. The concepts represent the "things" or entities that exist. A concept is labeled with two components: the conceptual type and the individual marker.

The **conceptual type** defines the category to which the entity belongs. For instance, in Figure 2 the concept `[Country:Philippines]` is an instance of the category `Country`, i.e., its conceptual type is `Country`.

The **individual marker** relates a concept to a specific object of the world. The object represented by `[Country:Philippines]` has the name (or value) `Philippines`. The individual markers may also be undefined. An undefined or generic individual marker is either blank or noted with a star `*`, if the individual object referred to is unknown.

The term **relation** is used to refer to a relation node. The relation nodes of a conceptual graph indicate the relations that hold between the different entities of the situation that is represented. Each relation node is labeled with a relation type that points out the kind of relation that is represented.

The notion of **vocabulary** was defined in (Chein and Mugnier 2008). The concept types and the conceptual relation types, which are used to label the concept and relation nodes, are organized in hierarchies.

Formally, we denote the set of concept types as T_C, the set of relation types as T_R and the set of individual markers that are used to labeled the concept nodes as markers, which defines a vocabulary $\mathcal{V} = (T_C, T_R, \text{markers})$. A basic conceptual graph G is then defined by a 4-uple $G = (C_G, R_G, E_G, l_G)$, where

- (C_G, R_G, E_G) is a finite undirected and bipartite multigraph. C_G is the set of concept nodes. R_G is the set of relation nodes, and E_G is the set of edges.
- l_G is a naming function of the nodes and edges of the graph G which satisfies:
  1. A concept node c is labeled with a pair $l_G(c) = (type(c), marker(c))$, where $type(c) \in T_C$ and $marker(c) \in \text{markers} \cup \{*\}$.
  2. A relation node r is labeled by $l_G(r) \in T_R$. $l_G(r)$ is also called the type of r.

Specialization and generalization of graphs

A specialization/generalization relationship is defined on the graphs. These relationships are used for the query function. The aim of the query is indeed to find all the sub graphs of the information graph that are specializations of the query graph. Therefore, the query is expressed as a generic graph.

Relationships between conceptual types

Given the hierarchical nature of the vocabulary, a partial order holds among the set of conceptual types T_C, interpreted as a relation of specialization: $t_1 \leq t_2$ means that t_1 is a specialization of t_2, that is to say that any instance of the class denoted by t_1 is also an instance of the class denoted by t_2.

Relationships between concepts

Given the order on T_C, we can also partially order the concepts that are defined on $T_C \times \{\text{markers} \cup \{*\}\}$, by a specialization relation as follows. Let $c_1 = [T_1 : m_1]$ and $c_2 = [T_2 : m_2]$ be two concept nodes, we define:

$$c_1 \leq c_2 \quad \text{iff} \quad \begin{cases} T_1 \leq T_2 \\ m_2 = * \quad \text{or} \quad sim(m_1, m_2) \geq thres \end{cases} \tag{1}$$

where sim is a similarity function and $thres$ a user-defined threshold. According to the different applications, $sim(m_1, m_2)$ and $thres$ may be defines empirically, after a statistical study or heuristically. In the present work, they are defined heuristically.

Relationships between graphs

We also define a specialization relation between graphs. This relation is denoted by $\sqsubseteq$ (in order to avoid confusion with the specialization relation $\leq$ between concepts). Let A and B be two basic conceptual graphs. C_A and $\mathcal{R}_A$ denote the set of concepts and relations of the graph A, defined over the vocabulary $\mathcal{V}$. Denoting as P_{AB} the set of graph isomorphisms between A and B, we have:

$$A \sqsubseteq B \Leftrightarrow \exists p \in P_{AB}, \begin{cases} p : C_A, \mathcal{R}_A & \rightarrow \quad C_B, \mathcal{R}_B \\ \quad c_A, r_A & \mapsto \quad c_B, r_B \\ \forall c_A \in C_A, & c_A \leq c_B \\ \forall r_A \in \mathcal{R}_A, & r_A = r_B \end{cases}$$

Semantic Information Fusion

We previously developed a framework based on graph structures, graph algorithm and similarity measures for semantic information fusion (InSyTo Laudy 2011). The InSyTo fusion framework encompasses a generic graph based fusion algorithm associated with fusion strategies. The InSyTo Synthesis fusion algorithm relies on subgraph isomorphism and maximum subgraph isomorphism algorithms. The idea is to find the largest subgraph of a first graph that cannot be distinguished from a subgraph of second graph. Maximal subgraph matching is used in order to determine where to add information in an information graph, and which parts of two information graphs are redundant and should thus be fused rather than be repeated twice in the graph resulting from the fusion.

The graph matching component takes care of the overall structures of the initial and fused observations. It is in charge of the structural consistency of the fused information, regarding the structures of the initial observations, within the fusion process.

The fusion strategy part is made of similarity, compatibility and fusion functions over elements of the graphs to be fused (see equation 1 for instance). They enable the customization of the generic fusion algorithm according to the context in which it is used.

Uncertain Information Fusion

In (Fossier et al. 2013), we introduced the management of uncertainty in the information fusion function. The approach is inspired by (Pichon et al. 2012) and based on the extension of the belief function theory (Shafer 1976; Smets and Kennes 1994). The extension enables using the theory within high level information fusion.

In this section, $\otimes$ denotes a fusion operator for the fusion of reliable observations about an event, as defined in the preceding section.

Let $\mathcal{M}$ be the knowledge model associated to a particular event of interest. Suppose we receive an observation $A \sqsubseteq \mathcal{M}$ about this event. Similarly as in (Smets 1993; Pichon et al. 2012), reliability in the present work means the following: if this observation can be assumed to be reliable, then our knowledge about the event becomes A, and if this observation is assumed to be not reliable, then it is not useful and must be discarded, which amounts to knowing nothing about the event. Note that in our approach, knowing nothing and knowing $\mathcal{M}$ about the event of interest are considered equivalent.

This classical view of the notion of reliability can be extended to the situation where we receive two observations A and B, as follows. There are four elementary cases to consider with respect to the reliability of these observations:

1. If they are both not reliable, then we discard both of them and we only know $\mathcal{M}$ about the event;
2. If observation A is reliable and observation B is not reliable, then we discard observation B and our knowledge about the event is A;
3. If observation A is not reliable and observation B is reliable, then we discard observation A and our knowledge about the event is B;
4. If they are both reliable, then we know $A \otimes B$ about the event.

The reasoning described in the previous paragraph can be formalized as follows. Let $\mathcal{H}_A = \{h_A, \neg h_A\}$ be the assumption space on the reliability of observation A, where h_A (respectively $\neg h_A$) denotes that observation A is reliable (respectively unreliable). Similarly, let $\mathcal{H}_B = \{h_B, \neg h_B\}$ be the assumption space on the reliability of observation B. The set of possible elementary assumptions on the reliability of these two observations is denoted by $\mathcal{H}_{A\times B}$ and defined by $\mathcal{H}_{A\times B} = \mathcal{H}_A \times \mathcal{H}_B = \{(h_A, h_B), (h_A, \neg h_B), (\neg h_A, h_B), (\neg h_A, \neg h_B)\}$. We can define a mapping $\Gamma_{A,B}$ from $\mathcal{H}_{A\times B}$ to $\Pi^*(\mathcal{M})$, which assigns to each elementary hypothesis $h \in \mathcal{H}_{A\times B}$, the result of the fusion of the two observations A and B. $\Gamma_{A,B}(h)$ indicates how to interpret these observations in each of their configuration $h \in \mathcal{H}_{A\times B}$. We have:

$$\begin{aligned}
\Gamma_{A,B}(h_A, h_B) &= A \otimes B;\\
\Gamma_{A,B}(h_A, \neg h_B) &= A;\\
\Gamma_{A,B}(\neg h_A, h_B) &= B;\\
\Gamma_{A,B}(\neg h_A, \neg h_B) &= \mathcal{M}.
\end{aligned}$$

The difficulty is that in general we have uncertain knowledge about the reliability of the observations. We consider in this paper that this uncertainty is represented by a probability distribution $prob^{\mathcal{H}_{A\times B}}$ defined on space $\mathcal{H}_{A\times B}$. Following (Pichon et al. 2012), this uncertainty is transferred through $\Gamma_{A,B}$ onto space $\Pi^*(\mathcal{M})$ in the form of a probability distribution $prob^{\Pi^*(\mathcal{M})}$ defined on $\Pi^*(\mathcal{M})$ by:

$$prob^{\Pi^*(\mathcal{M})}(C) = \sum_{h:\Gamma_{A,B}(h)=C} prob^{\mathcal{H}_{A\times B}}(h), \quad \forall C \in \Pi^*(\mathcal{M}).$$

In this context, $prob^{\Pi^*(\mathcal{M})}(C)$ is the probability that our knowledge about the event of interest be in the form of conceptual graph $C \sqsubseteq \mathcal{M}$. In short, it is the probability of knowing C. For instance, we may assume that observations A and B have independent probabilities q_A and q_B, respectively, of being reliable, in which case we obtain:

$$\begin{aligned}
prob^{\Pi^*(\mathcal{M})}(A \otimes B) &= q_A \cdot q_B;\\
prob^{\Pi^*(\mathcal{M})}(A) &= q_A \cdot (1 - q_B);\\
prob^{\Pi^*(\mathcal{M})}(B) &= (1 - q_A) \cdot q_B;\\
prob^{\Pi^*(\mathcal{M})}(\mathcal{M}) &= (1 - q_A) \cdot (1 - q_B).
\end{aligned}$$

The extension of this approach to the case of more than two partially reliable observations does not raise any theoretical issue. One should be only be aware that the order in which observations are handled may matter depending on whether $\otimes$ is associative.

The belief function theory is extended as follows. Let $prob^{\Pi^*(\mathcal{M})}$ represent our uncertain knowledge about an event of interest. It may for instance be the result of the merging of several partially reliable observations according to the scheme above.

It is insightful to remark that $prob^{\Pi^*(\mathcal{M})}$ is quite close formally to a mass function (Shafer 1976; Smets and Kennes 1994), since a mass function on a finite set Ω is formally a probability distribution on the power set of Ω. Indeed, this comparison can be used to define some concepts inspired from belief function theory, in the present knowledge representation framework, which deals with uncertain and soft knowledge. In particular, we may define the degree of support (or degree of certainty) $Sup(A)$ of a conceptual graph $A \sqsubseteq \mathcal{M}$ as:

$$Sup(A) = \sum_{B \sqsubseteq A, B \neq \diamond} prob^{\Pi^*(\mathcal{M})}(B).$$

This definition is directly inspired from the definition of the belief function associated to a mass function (Shafer 1976; Smets and Kennes 1994). Its introduction is motivated by the fact that in some problems, such as the one of finding clues of the veracity of an hypothesis, we may only be interested in a given graph $A \sqsubseteq \mathcal{M}$ and in particular by how much the knowledge derived from the available observations supports this graph.

RUMOR DETECTION

In this paragraph, we describe the four core functions on which our rumor detection approach relies. The core functions rely on the use of the above described semantic graph fusion approach (Laudy 2015).

Table 1. Event type keywords

Event types	*Keywords*
Accident	accident, crash, onnettomuus
Crash	crash
PlaneEvent	plane, airport
TerroristAttack	terrorist, hostage, attack
TrainEvent	train
Fire	fire, palokunta

Event Typing

In order to detect rumors a soon as possible, our approach relies on the deep analysis of the tweets spread during and related to a crisis situation. The first step of this deep analysis is to type the event descriptions (i.e. the tweets), according to the type of event they describe. The possible event types are defined in a domain ontology. In our further examples, we use the type hierarchy depicted in Figure 3.

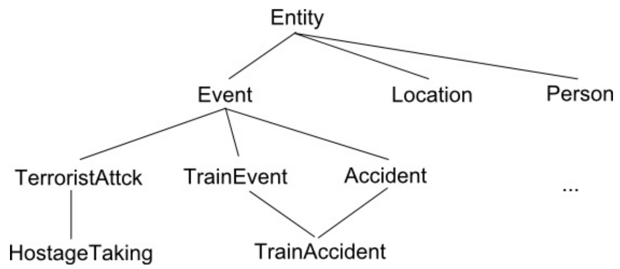

Figure 3. Example of (event) type hierarchy

To type the events, as in the approach presented in [SunEtAl], we use a data set of types event keywords. This data set is a table associating keywords to one or more event types (see Table 1 for an example). As keywords are detected in a tweet, all possible event types are selected. The type finally associated to the event is the most general common subtype, according to the domain ontology.

For example, the following tweet will be typed as follows :

- Sentence: Policemen told us rocks on the rails caused the crash of the freighted train
- Potential event types : [TrainEvent, Accident]
- Selected event type : TrainAccident

Event Fusion

The unitary event fusion step aims at reducing the amount of information an operator has to monitor, by fusing into a single event report, all the information items contained in several tweet messages reporting the same event. This fusion is realized following the semantic information fusion approach described previously.

The tweets related to the same crisis situation are processed through the InSyTo fusion framework, so to provide the end users (PSOs) with a synthetic and non-redundant description of the situation. This synthetic description is used to provide information to the other levels of command in the crisis management center.

As explained before, the event descriptions are fused by giving the most precise description that contains all the elements of the initial tweets. In particular, the type of the fused event description is the most generic common subtype of all the initial events. As a matter of example, lets consider the following tweets.

- T1: “Policemen told us rocks on the rails caused the crash of the freighted train.”
- T2: “Terrible smell near the train.”
- T3: “RT Policemen told us rocks on the rails caused the crash of the freighted train.”

Table 2. Example of unitary typed event reports

Event type	*Content*
TrainAccident	Policemen told us rocks on the rails caused the crash of the freighted train.
TrainEvent	Terrible smell near the train.
TrainAccident	RT Policemen told us rocks on the rails caused the crash of the freighted train.

They will be typed into the unitary event reports as shown in table 2. The fusion of all unitary reports, given a strategy that concatenates text messages if they are different, will produce the following fused event report :

- TrainAccident : "Policemen told us rocks on the rails caused the crash of the freighted train. Terrible smell near the train"

It is to note that given that tweets encompass meta-data such as authors names, dates of publication and localization, the fusion strategy may be 'smarter" and take these meta-data into account in order to obtain better results.

Conflicting reports detection

The potential rumorous tweets are detected thanks to their semantic analysis and using the above mentioned typing and fusion approaches. Whenever no common subtype can be found for a set of events, the fusion process results in several descriptions of several incompatible events. In such cases, an alarm for potential rumorous tweets is raised.

As a matter of example, let us consider the following tweets, collected in a crisis situation.

- T1: "Policemen told us rocks on the rails caused the crash of the freighted train."
- T2: "Terrible smell near the crashed train: it contained ammonium."
- T3: "They say the train drivers have been killed by a chemical terrorist attack!"

T1 will generate an event of type TrainAccident, T2 of type TrainEvent and T3 of type TerroristAttack. As it can be seen on Figure 2, T1 and T2 may be fused in order to generate an event of type TrainAccident, which is not compatible with the type of third event. Thus, incompatible reports are detected and we raise an alarm for potential rumorous activity. The PSO are able to check it and act so to avoid the rumor to spread widely.

Hypothesis Evaluation

A potential rumor is detected, PSO have to verify the veracity of the informations in order to check whether an emerging event is a rumor or a real emergency. As stated before, the evaluation of the reliability of the messages received by the PSO is important. The reliability will depend on the source of information, and the credibility granted to this source. However, when aggregating and fusing information coming for different sources, one must still monitor the reliability of the overall fused information.

Hypothesis evaluation enables the evaluation of the degree of certainty one may grant an event, given all the information available on this event. The testimonies and descriptions are scored according to the degree of confidence the PSO have in this information. It is either done manually according to PSO expertise of the types of events, types of testimonies and source of the testimony or information. Or the evaluation may be supported by tools.

Hypothesis evaluation is the query for degree of certainty that a specific situation or event is on-going. When the PSO want to evaluate the level of certainty that an event occurred or is on-going, they query the available information items on this event. Given the degree of certainty associated with each information item, a global evaluation of the veracity of the event is processed.

The approach used for hypothesis query, is the uncertain information fusion approach described above.

EXPERIMENTATIONS

The work presented here was applied within two European funded projects the iSAR+ project *iSAR+ Project* 2012 and the SOTERIA project *SOTERIA Project* 2014. Several experimentations were performed. The evaluations of our work were conducted in two phases:

- Within iSAR+ project, we tested the detection of reports of events of a new type during the proceedings of a crisis.
- During the SOTERIA project, we coupled the possibility of evaluating the hypothesis that a new event is verified or is only a rumor.

iSAR+ Experimentations

iSAR+ project gathered together 16 partners from 8 European countries. One of the objective was to develop a platform dedicated to ease communication between citizens and PSO during crisis. Several experimentations were conducted during the project. Detailed information about these experiments can be found in iSAR+ document D7.731 (see *iSAR+ Project* 2012).

Among others, the second experimentation took place in France, in near to real conditions. The scenario took place in a big train station and included several emergency events: an unattended luggage found and the start of a fire in technical premises near to the metro. The citizens were played by Red Cross volunteers and students. Their role was to broadcast information on social network and behave as asked by authorities through social media platforms and other communication means.

Numerous tweets were sent notifying the abandoned luggage and bringing attention to a potential terrorist attack. An alarm was triggered and information sent to citizens on their smart-phones. The luggage owner was found and the rumor blocked through information of actual situation to the citizens.

In the second part of the scenario, numerous citizens reported the smoke, thus the PSO were advised of the situation both from regular calls to the 112 and through their twitter account. Instructions were given to citizens by PSO in order to evacuate the metro station. The fusion function enabled to gather tweets and re-tweets about the event and provide the PSO with a single event report, made of an aggregation of all the initial tweets.

The experiment was a success and tools were assessed as useful and easy to use. We collected feedback from several PSO, among others the followings.

- A colonel for Gendarmerie (78 department) assessed his interest for *"intelligent tool able to qualify information collected on social networks"*.
- A PSO from SDI 78 assessed his interest for social networks, but states that *"the information should be qualified and reliable"*.

SOTERIA Experimentations

The SOTERIA project took place as the continuation of iSAR+. The hypothesis evaluation function described before was tested during the last experimentation of the SOTERIA project. The experimentation was held in Portugal, and officers from Guarda Nacional Republicana (GNR) tested the tools. The scenario of the use case comprised an earthquake resulting in building collapsing, chemical and biological contamination of population and road accident close to the river.

As numerous events occurred in the same area, the information fusion and conflicting report detection capabilities were very welcome by PSO officers. Thanks to hypothesis evaluation, they could also distinguish between new event reports about an actual emergency or ongoing rescue operation (reported both by PSO and citizens with lower level of trust) and rumors of terrorist attacks when GNR drones flew over the experimentation zone.

Hypothesis evaluation limitations

The hypothesis evaluation capability has been acknowledge as being critical for the use of social media based information within crisis and emergency management. However, the information evaluation function relies on an extension of the belief function theory. The extension enables using the theory within high level information fusion. The belief function theory relies on the comparison of the entire possible hypothesis regarding the reliability of a proposition. These hypotheses are generated by combining all the observations and their level of reliability. Within the Soteria platform, this means that we combine a set of reports that are provided to OZONO, taking into account the reliability of the source that provided the report. For instance a report sent by a PSO will be more reliable that a report sent by a citizen. As we can see, the approach itself, by nature is highly combinatorial. This comes out as a very time consuming process, with regards to the number of reports that are considered. Therefore, the current state of the service does not enable to process a sufficient amount of information in order to be useful within emergency context, where a lot of messages may be sent to PSO by citizens that are experiencing the emergency.

CONCLUSION AND FUTURE WORK

In this paper, we propose an approach for conflicting information and rumor detection on social media platforms. The aim is to support PSO officer in their monitoring of information spread on social media.

We first described the semantic information fusion approach on which we rely. It is based on the use of semantic graph structures for information representation, and graph matching algorithms for information fusion. Uncertainty management capabilities were added to the graph fusion algorithms, in order to provide means to evaluate the credibility one may grant an hypothesis, based on the credibility of the different testimonies verifying and refuting this hypothesis.

We then explained how semantic information fusion was used in the aim of detecting conflicting information reports as well as evaluating the risk that an information is rumorous.

Finally, as the developed functions were deployed and tested during campaigns of experimentations, we assessed the usefulness of such capabilities for crisis and emergency management support tools dedicated to PSOs. We also witnessed to limitation of our approach for evaluating large amounts of uncertain information.

Future research work will focus on this last point. Previous work on the parallelization of graph based information fusion were achieved using the Hadoop framework (Laudy et al. 2014). Adapting the uncertainty management approach to parallel computation is one of the direction we will focus on.

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Social Media during a Sustained Period of Crisis: The Case of the UK Storms

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ABSTRACT

This paper analyses the social media communications surrounding the 2015 - 2016 series of winter storms in the UK. Three storms were selected for analysis over a sustained period of time; these were storms Desmond, Eva and Frank which made landfall within quick succession of one another. In this case study we examine communications relating to multiple hazards which include flooding, evacuation and weather warnings using mainstream media content such as news stories, and online content such as Twitter data. Using a mixed method approach of content analysis combined with the application of a conceptual framework, we present (i.) the network of emergency responders managing events, (ii.) an analysis of crisis communications over time, and (iii.) highlight the barriers posed to effective social media communications during multi-hazard disasters. We conclude by assessing how these barriers may be lessened during prolonged periods of crisis.

Keywords

Social media, disaster management, conceptual framework, emergency coordination, information overload

INTRODUCTION

Social media are increasingly utilised for the dissemination of information throughout all phases of the disaster life cycle (Ruggiero & Vos 2014; Haddow & Haddow 2013; Alexander 2013). Individuals may rely on social media as a source of information required to make personal and complex safety critical decisions during crisis situations (Carver & Turoff 2007). Similarly emergency responders and organisations managing such events may rely on multifaceted networks of skilled individuals, bodies, policies and protocols (Huang et al. 2010). Social media offers a range of supporting features which may reduce risk during crises: real-time monitoring and evaluation can be used for targeted action purposes (Ruggiero & Vos 2014), generalized monitoring and evaluation may support policy-making (Sobkowicz et al. 2012), and as a means to establish situational awareness (Anderson et al. 2014). Specific to disaster management, social media may provide warning systems throughout life cycle phases (Sweta 2014), identify or track potential hazards or problems (Crooks et al. 2013), and strengthen human interaction, coordination and crisis communications (Lindsay 2011).

Using social media as a means to disseminate time-critical information does however face obstacles. Information overload transpires when there are high volumes of accessible information which may not be relevant or useful to individuals or bodies (Bharosa et al. 2009). Often this occurs when information is not entirely related to a specific situation, is not targeted at particular individuals or networks, or is simply outdated, making reliability of sources a problem (Lu & Yang 2011; Westerman et al. 2014). Furthermore, poor communication and uncoordinated dissemination from emergency responders and bodies managing crisis situations may further exacerbate these problems (Shklovski et al. 2008). Despite a rise in global connectivity through developments in technology, such as the World Wide Web, accessibility to social media remains a significant obstacle (Wentz et al. 2014). Factors such as social class, gender, ethnicity, income and geographical location may all impact one's ability to access social media and other online resources (Fothergill et al. 1999; Haddow & Haddow 2013). Analysis of particular social media platforms, predominantly Twitter, are growing in number within the field of disaster management for their ability to disseminate tailored and succinct information rapidly in time-critical situations (David et al. 2016; Hughes & Palen 2010).

In addition to tackling barriers posed by social media there is a growing need to analyse the causes and impacts of high magnitude and multi-hazardous disasters which are becoming more common and devastating than previously expected (Kappes et al. 2012; Kousky 2014; Lung et al. 2013). The term multi-hazardous is applicable to disasters where a combination of hazards occur within quick succession of one another, and in a particular geographical region. The hazards must interact, trigger, exacerbate the effects of, or compound other hazards (UN/ISDR 2009). Such events are likely to increasingly become the focus of disaster management strategies due to underlying or preexisting processes and events such as pollution or climate change (Blaikie et al. 2014). Effective coordination and crisis communications by emergency responders and bodies involved in managing events must be timely, reliable, and uniform in content across multiple social media platforms (St. Denis et al. 2014). A number of recent studies have been conducted which assess social media during such events where platforms can provide new functionality during disasters, for example: using Twitter as a distributed sensing sensor system for hazards (Crooks et al. 2013), using cloud-based systems and cyber-infrastructure to build online communities to cope with disasters (Wan et al. 2014), building Web-based decision support mechanisms (Hadiguna et al. 2014), and the creation of early warning systems which utilise particular social media platforms (Sweta 2014).

This paper contributes to current knowledge by demonstrating the change in Twitter content over a sustained period of crisis that featured multiple disaster events in a bounded geographical region. Unlike similar studies which take into account change in Twitter content throughout the pre-disaster, during, and post-disaster lifecycle phases, this study assesses content throughout the lifecycle phases for three separate storm events during a period of three months (December 2015 until February 2016). This demonstrates that the function of Twitter changed not only over time, but also as a result of multi-hazardous events which were, in some cases, caused or exacerbated by previous hazards. Unlike a majority of similar studies, the Twitter data was compared with information collected from mainstream sources such as newspapers and news broadcasts. This allowed the study to cross-reference events across multiple sources resulting in a clearer analysis that reduced the risk of potential contradictions between online vs. offline information. To demonstrate this the study applies a conceptual framework proposed by Gray et al. (2016) to provide a categorical understanding of the uses and users of Twitter and how this changes over time. This contributes to the field by offering a better understanding of how categorical use of social media is affected by overlapping disaster lifecycles and the presence of multiple hazards which occur within quick succession of one another. The paper concludes with suggestions for the future management of multi-hazard disasters over a sustained period, and identifies steps for data analysis which may further the work presented in this paper.

THE STUDY

Rationale for Analysis

Many studies have demonstrated that Twitter content changes during the disaster lifecycle of a particular event, see for example (Hughes & Palen 2010). However, few have evaluated changes in content during overlapping phases of the disaster lifecycle. In such periods of time, the way in which people engage with social media is blurred (Houston et al. 2012). Someone may be using it to spread early warnings - which is characteristic of the pre-disaster phase (Jin et al. 2011) - whereas another person may be using the same function, at the same time, to get into contact with a loved one – which is characteristic of the post-disaster phase (Simon et al. 2015). Therefore, data sets for each of the storms were collected separately to preserve the information cycle of each disaster. Each data set was later cross-referenced with the others, as well as with the offline information gathered in the form of media updates and news stories.

Storms Desmond, Eva and Frank were the three largest and most destructive storms of the UK winter storm season which featured eleven meteorological events in total. The season began in early November 2015, and dissipated in late March 2016, illustrated in figure 1 below. Each of the selected storms were contained to a relatively small region of northern England which meant that the emergency responders and bodies managing events remained the same throughout this period. Similarly, the populations affected remained unchanged throughout each of the meteorological events making direct comparisons in management and effectiveness more insightful over a sustained period of time.

Background Information

The unusually intense storm season was associated with a strong westerly airflow in the Eastern seaboard of the US. Due to colder ocean temperatures over the North Atlantic a strong temperature gradient formed which strengthened the jet stream and formed rapidly deepening cyclones, such as Storm Frank, Desmond and Eva. The Met office issued warnings for North East England where the storm systems were due to make landfall throughout December, increasing in severity prior to the landfall of storm Desmond. From the December 1st - 4th areas experienced continuous rain which made large expanses of ground saturated, and winds over 70mph, warranting a severe storm hazard to public safety. Following landfall, record rainfall caused further hydrological hazards. Later, the overly saturated ground triggered a major subsidence of land in a wet mass movement hazard, blocking many road and national rail links. Hydrological hazards such as high velocity floodwaters and extreme surface runoff caused infrastructure damage to bridges, roads and pathways resulting in traffic hazards.

Warnings to the public regarding safe movement were issued through multiple media channels which increased after several deaths occurred due to floodwaters. Debris from other hazards swept down river channels with the potential to cause damming, or to harm the surrounding environment. From December 6th - 10th floodwaters submerged one or more floors of more than 1,000 properties, warranting emergency evacuations and rehabilitation. Flooding damaged local electricity suppliers causing a technological hazard where more than 6,000 properties across Cumbria to lose power. Later on in the month severe weather warnings were issued for storm Eva which made landfall on December 23rd and featured winds of 84mph. High rainfall exacerbated flooding caused by storm Desmond and lead to a total of more than 3,000 further power outages. Further disruption was forecast by the arrival of storm Frank, resulting in additional severe flood warnings. The storm made landfall on December 29th causing the collapse of several local bridges, and crippled local transport systems across Cumbria, and in several towns in Scotland. A timeline of events is shown in figure 1 below.

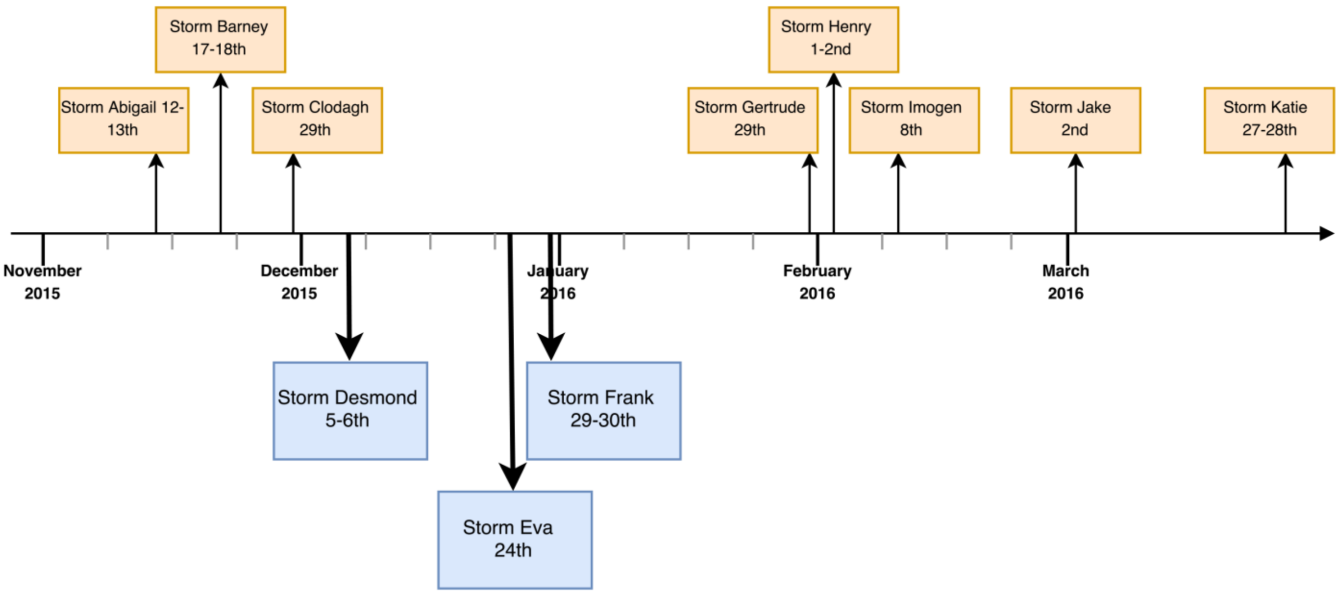


Figure 1. A timeline of the storms which made landfall in the UK from November 2015 – March 2016.

METHOD

Data relating to storms Desmond, Eva and Frank was collected using online content, such as Twitter data and blogs, and mainstream media content, such as news broadcasts. This provided a detailed timeline of events that could be cross-referenced with one-another, resulting in a more accurate understanding of how the offline vs. online events differed during a sustained period of crisis which featured multiple hazards. Content analysis was conducted on Twitter data collected for featuring key terms ("Storm Desmond", "Storm Frank, and "Storm Eva"), as well as the application of a conceptual framework for the classification of the uses and users of social media over time. Each of the methodology sections below are listed in chronological order of their occurrence.

Twitter Data

Twitter data was collected for storms Desmond, Eva and Frank using the Twitter streaming API. This produced roughly 127,000 tweets in total. Tweets were collected for featuring specific terms which are shown in table 1 below. As the collection terms are general it is important to note that the content may be biased towards accounts and individuals who are more heavily using these terms compared to others. This has been addressed in the latter 'Future Work' section.

Table 1. Search terms for tweet collection and number of tweets collected per term.

Search Term	Number of Tweets
Storm Desmond	10,418
Storm Eva	12,835
Storm Frank	105,474

Content Analysis

An infoveillance approach was adopted to track popular terms and hashtags over time (Chan et al. 2013; Pagliari et al. 2016). Between December 2015 and February 2016 tweets were collected into three data bases corresponding to each of the search terms in table 1 above. Tweets were systematically selected for a whole 24-hour period at 7 day intervals for each of the search term data sets, beginning at the pre-disaster phase of storm Desmond (chronologically the first storm selected for analysis, December 2015). These smaller datasets can therefore be considered "sub-samples". This avoids problems with the large size and velocity at which content is created and re-tweeted on Twitter during disasters, while demonstrating content change over the course of three months (Hoeber et al. 2016).

Content analysis was conducted after systematic sampling. This was firstly done automatically by python scripts, and then manually by the researchers which indicated: (i.) the most popular terms and hashtags over time, (ii.) the most active accounts over time with regard to creation of information (for example, new weather warnings), (iii.) the most active accounts in terms of information dissemination (for example, retweeting), and (iv). the nature of crisis communications both between emergency responders and bodies managing the event, as well as between these bodies and the public. Offline content analysis was collected in parallel to the Twitter data from newspapers and updates published by organisations manually. This was used by the researchers to create a timeline of online as well as offline events which could be cross-referenced with one another.

Conceptual Framework Application

Following content analysis, the conceptual framework proposed by Gray et al. (2016) was applied to the systematically sampled data sets to show change in social media content over time. The application of the framework was conducted manually by the researchers in which tweet content was read, and a framework category (or multiple) was assigned to the content. The framework is shown in Table 2 below, and was created by inductively coding a range of disaster management literature from the previous five years to ascertain current uses and trends of social media during crises. This indicated that the uses of social media categorised from literature were present in the data, and showed how they changed in nature throughout a sustained period of crisis.

Table 2. The conceptual framework proposed by Gray et al. (2016) showing the users and uses of social media throughout the disaster lifecycle phases.

Disaster lifecycle phase	The uses of disaster social media
All stages	1. Evaluate the reliability of information 2. Identify and/or contain false information
Pre-event	3. Provide and seek general disaster preparedness information 4. Provide and receive general national and regional disaster warnings
Pre-event → During	5. Detect and warn of disasters and specific hazards locally 6. Identify the differences between actual and potential uses of social media
During event	7. Send and receive requests for help or assistance 8. Inform others about ones condition and location
During → Post-event	9. Provide, receive and analyze big data generated by the event 10. Provide, receive and encourage information sharing in multiple formats 11. Document what is happening during a disaster online and offline 12. Consume or create news coverage of the disaster 13. Provide and receive location based real-time warnings 14. Express public and/or individual emotion or empowerment; reassure others 15. Raise and develop awareness; donate and receive donations; list ways to help or volunteer 16. Seek to inform and support existing disaster management strategies 17. Provide and receive specific disaster response, rescue and evacuation information 18. Seek and assess mental, behavioral and emotional health support 19. Filter, categorize critically analyze information 20. Understanding how online and offline situations differ 21. Provide and receive information regarding disaster response, recovery and rebuilding; tell and hear stories from the disaster 22. Understand how ones access to the Web has had an effect on their experiences
Post-event	23. Discuss socio-political causes, implications and responsibility 24. Re-connect community members 25. Discuss the accessibility of the Web as an intermediary to social media 26. Discuss the accessibility and reliability of specific social media; discuss perceptions
Post-event → Pre-event	27. Consolidate lessons learnt to develop new/improved social media applications

RESULTS: COMMUNICATIONS OVER A SUSTAINED PERIOD OF CRISIS

Content analysis of offline data showed more than 100 agencies created, discussed or disseminated information regarding storms Desmond, Eva and Frank. These fell into four main categories: branches of government, commercial organisations, self-funded organisations, and media outlets. Manual analysis of online Twitter data sets for each storm, before systematic sampling took place, totaled 127,000 tweets. Between December 2015 and February 2016 data showed that emergency responders sustained high levels of public engagement through offline channels such as news broadcasts, as well as online channels such as Twitter, blogs and other social media platforms like Facebook (table 3 below). The most active emergency responders and organisations on Twitter throughout the storm season remained similar (table 4), indicating that the level of interagency coordination for the regions affected was effective and consistent. Information was created by a select few Twitter accounts managing the hazards, whereas dissemination of information was spread by a larger range of accounts, which included; emergency services, metrological services, transport services, government, local companies, charities and voluntary groups, members of parliament (MPs), celebrities, researchers and members of the general public (table 3 below).

Table 3. The top Twitter accounts who both tweeted and were re-tweeted the most during storms Desmond, Eva and Frank.

Storm Desmond	Storm Eva	Storm Frank
HelpTheNorth	HelpTheNorth	todayCork
UKFloods	NationalRailEnquiries	EmergencyIE
AlimdaadUK	EmergencyIE	FloodsUK
QSFLancaster	TheBDMA	TheBDMA
TheBDMA	FloodsUK	AlimdaadUK
FloodAlerts	ElectricityNW	TrafficScotland
MKA UK	jeremycorbyn	BBCWeather
ITVborder	METoffice	METoffice
ClarenceHouse	BBCNews	BBCNews
Foragaid	EnergyDesk	NationalRailEnquiries

Table 4. The top Twitter accounts who were tweeted at the most during storms Desmond, Eva and Frank.

Storm Desmond	Storm Eva	Storm Frank
@AlimdaadUK	@AlimdaadUK	@BBC_Cumbria
@BBC_Cumbria	@BBCNews	@BBCScotland
@ClarenceHouse	@ElectrictyNW	@AlimdaadUK
@FloodAlerts	@CumbriaPolice	@CoastguardTeam
@HelpTheNorth	@EnergyDesk	@CumbriaPolice
@KTCouncil	@HelpTheNorth	@metoffice
@MKA_UK	@JeremyCorbyn	@RNLI
@Forageaid	@metoffice	@TrafficScotland
@ITVborder	@nationalrailenq	@scotgov
@ElectricityNW	@SkyNews	@bbcweather

Manual content analysis of the data showed that Twitter accounts were categorised as being either “official” accounts representing an organisation, group or other type of body, or “unofficial” accounts representing members of the public. Only a relatively small number of official accounts were seen to create information from December 2015 to February 2016 (table 3). Of these accounts, a majority were consistent throughout the sustained period of crisis, and throughout each of the storms. This resulted in the formation of an online network where official accounts acted as hubs (accounts who address user messages) and authorities (accounts that receive tweets from other accounts) (Adar & Adamic 2005; Manoj & Baker 2007) that individuals directed messages and tweets at (table 4 above). Some accounts, for instance @jeremycorbyn, received a high amount of public interaction for other motivations i.e. political.

Changes in Twitter Content

Manual content analysis of the storm data used python code to automatically count the most popular hashtags, terms, re-tweets and most active Twitter accounts within the data. Analysis corroborated conventional Twitter findings: firstly, a majority of retweets which featured the most popular terms were largely directly linked to the storm events (table 5 below). Secondly, unofficial accounts had the highest proportion of retweets that cited original sources of information. Thirdly, the most retweeted tweets and/or accounts were official accounts, which generally were directly involved with the management of the storms throughout the period of crisis. Finally, it is important to note that due to the quick succession of the storm’s occurrence that there is crossover between popular terms across the datasets. This represents a difficult problem for the analysis of social media during sustained periods of crisis as information from multiple stages of the disaster lifecycle may still be in circulation at the same time. Crossover terms between datasets nonetheless remain important to analyse as they remain a part of the overall picture which individuals engage and react to regardless of lifecycle phase.

Table 5. The top 10 most popular tweet terms and their count for storms Desmond, Eva and Frank.

Storm Desmond Popular Terms	Count	Storm Eva Popular Terms	Count	Storm Frank Popular Terms	Count
FloodAware	2641	Cumbria	1479	Cork	2527
MuslimsForHumanity	1122	StormDesmond	882	Floods	2463
CumbriaFloods	1016	Flooding	620	CorkFloods	1799
Desmond	920	StormFrank	478	Weather	1536
Cumbria	642	Floods	437	Flooding	1205
ShowYouCare	640	CumbriaFloods	435	StaySafe	977
Keswick	302	UKfloods	320	FloodAware	869
StormFrank	242	ChristmasEve	276	Storm	834
Muslim	236	MuslimsForHumanity	264	StormGertrude	807
StormEva	158	Ireland	221	Flood	788

Organisations involved in the management of the storms produced a relatively small proportion of tweets. Although many organisations had a physical presence in affected areas, only a handful of these created and disseminated online information during time-critical situations. This indicates that organisations coordinating in the real-world had incorporated a structured online presence where only selected accounts created new data. The primary account for this was the Cumbria Police who created and disseminated updates, information and advice that was tailored for the public in areas that were affected by the disaster. The content produced was then re-tweeted and shared by other coordinating organisations, for example the Environment Agency. Other regional accounts, such as BBC Cumbria and Help the North were responsible for the largest amount of re-tweets. The British Damage Management Agency (BDMA) were responsible for generating the largest amount of tweets featuring the term "#stormDesmond", "#stormEva" and "#stormFrank". Unlike the Cumbria Police, The BDMA produced generalised content designed for the wider public by using general hashtags.

The Alimdaad Foundation UK was unexpectedly responsible for a large amount of tweets, as well as a large amount of retweets. This is explains the popularity of the terms '#muslim' and '#MuslimsForHumanity'. This was because the foundation, in a gesture of unity and community welfare, dedicated time, resources and volunteers to areas that were badly affected by the storms. Consequently, this generated a flood of online information within the storm events as the involvement of the group was regarded as a socio-political event. Other types of update were created and disseminated by accounts such as the Met office and FloodAlertsUK who focused on communicating weather warnings and developments for meteorological hazards only. This ensured that the information they were producing did not conflict with that produced by other organisations. Popular terms associated with these also featured geographical areas that were also affected by the storm systems outside of Cumbria, i.e. '#Cork', '#CorkFloods'.

Changes in Framework Categories

Twitter content published within the first two weeks of December 2015 featured early disaster lifecycle phase categories which fell primarily into categories 3 'provide and seek general disaster preparedness information', and 4 'Provide and seek general disaster preparedness information' (Figure 2 below). Local citizens published regional information from personal experience, such as remote flooding and updates about the condition of local flood defences. A majority of tweets that fell into these categories however took the form of automated updates about the weather or developing hazards that were generated by official accounts such as @METOffice, which were then re-tweeted by a large number of Twitter users. Dissemination of re-tweets occurred within quick succession of the original updates, and petered out commonly within an hour. This suggests that the information spread was timely, and that the intervals between official updates were low. Additionally, as the disaster unfolded category 14 'Express public and/or individual emotion or empowerment; reassure others' increased. This may represent the desire of individuals and communities to express solidarity during crises, often using whatever medium they can (a phenomenon well-documented in similar studies, see for example St Denis et al. 2014).

Content published during the end of December 2015 featured during to post disaster lifecycle phase categories, which primarily took the form of 11 'Document what is happening during a disaster both online and offline' (figure 3 below). Official accounts (many of which featured in table 4 above) addressed concerns raised by individuals who were situated in isolated rural areas who had reduced access to the Web due to network coverage, and therefore needed direct, reliable and clear updates regarding hazards nearby. In contrast to similar case studies, tweet content did not reveal public confusion or contrasting information. This indicated that the organisation of accounts involved in the management of storms were successfully mitigating the negative effects of information reliability during crisis situations, which furthermore continued for an extended duration after the initial hazard had dissipated. Figure 3 also shows that the spread of other during-post categories were more evenly spread than in figure 2. Categories 4 and 8 are most likely explained by the fact that the early stages of storm Eva had occurred. Categories 15 'Raise and develop awareness', 21 'provide and receive information regarding disaster response, recovery and rebuilding; tell and hear stories from the disaster' were used for updates regarding the clean-up and re-building of areas damaged by storm Desmond, but also by the public to express personal experiences to raise national and international awareness.

During the beginning of January 2016 there was a much more complex spread of categories recorded in the data (figure 4 below). Categories from all of the disaster lifecycle phases were recorded, showing that a large amount of data being created and disseminated originated from multiple disasters. Category 12 'Consume or create news coverage of the disaster' was most likely linked to the early stages of storm Frank and the latter stages of storm Eva. On the other hand, category 23 'Discuss socio-political causes, implications and responsibility' was linked to the post stages of storm Desmond where the public were beginning to question and debate the extent to which the UK government could have managed the situation better.

Figure 2. A pie chart showing the largest percentages of categories from the first subsample of storm Desmond tweets (15/12/2015).

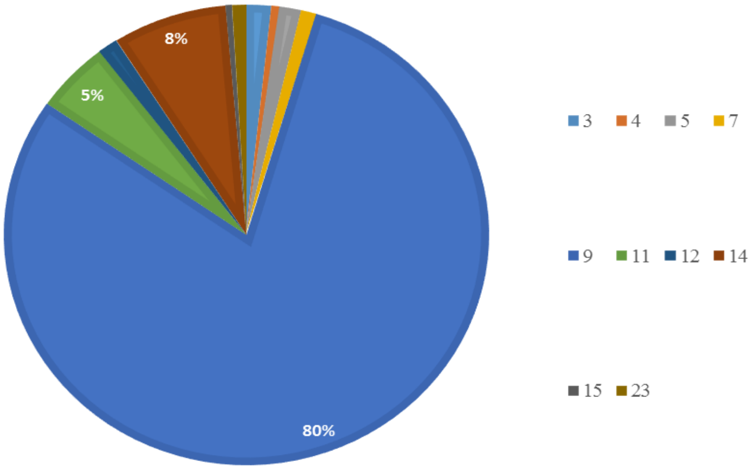


Figure 3. A pie chart showing the largest percentages of categories from the first subsample of the storm Eva tweets (29/12/2015).

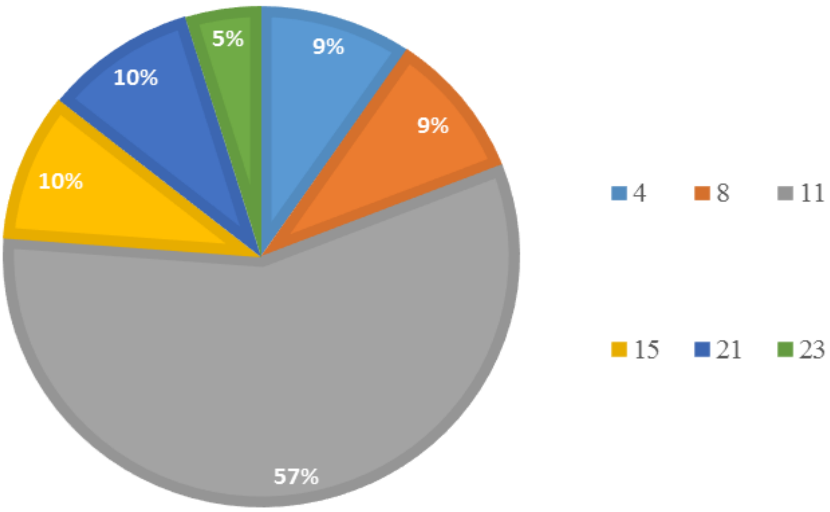
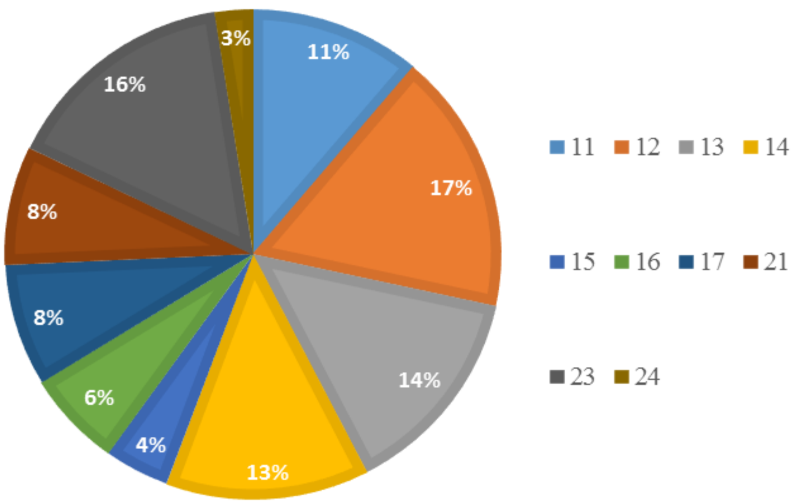


Figure 4. A pie chart showing the largest percentages of categories from the first subset of storm Frank tweets (04/01/2016).



DISCUSSION

Reducing Information Overload

Information overload remains a barrier to the effective use of social media during disasters (Hiltz & Plotnick 2013). The extent to which information overload is considered a barrier varies with the intention to use it as a disaster management tool in itself (Rao et al. 2017). Agencies and organisations seeking to effectively use online disaster management strategies therefore must consider more unified methods to tackle information overload. Higher priority should be placed on the software and applicability of tools to lessen overload across multiple platforms, as well as on the importance of developers collaborating on a standard toolkit which may easily be integrated between organisations (Rao et al. 2017). In addition to overload, the problems of information dearth, credibility, and online human behavior must be increasingly taken into account. The way in which people use, engage with, and perceive social media during disasters evolves with the development and uptake of new technologies, social media platforms, services and applications (Abdullah et al. 2017).

Reducing the Future Impacts of Multi-Hazard Disasters

Multi-hazardous disasters are predicted to increase in severity and frequency in the near future, and as such require further analysis (Fleming et al. 2014). Disaster management strategies using a multi-hazard approach rely on information for decision making processes. Although more collaborative development of tools and software is required for the ease of sharing information between agencies, social media should not be analysed in isolation (Fleming et al. 2014). Future research should consider integrating social media analysis with other qualitative methods to produce more comprehensive understanding of crisis situations in general, but also particular case studies that may facilitate future lessons (Liu et al. 2016). Mixed method and multi-hazardous approaches are vital to shed further light to disasters case studies, especially those which are sustained over a long period of time or that feature disasters in different phases of the disaster life cycle (Jin et al. 2011; Liu et al. 2016).

CONCLUSION

In conclusion, this study analysed Twitter communications during storms Desmond, Eva and Frank from December 2015 until February 2016. Communications discussed multiple hazards, which included flooding, evacuation and weather warnings using mainstream media content such as news stories, and online content such as Twitter data. Both manual and automatic content analysis using python scripts demonstrated how the general uses of social media changed, not only throughout the disaster life cycle phases for each storm, but also how the content was influenced by hazards associated with the other storms occurring in quick succession. Despite the presence of well-coordinated management efforts the study highlights that the barrier of information overload during multi-hazardous events poses future risk. This may be addressed by developing software and tools that can be applied universally across social media sites, and can be integrated between organisations with ease. Crisis communications during the course of the storms further highlighted that case studies where severe hazards occur within quick succession and frequency require further investigation as they are predicted to grow in magnitude and severity with the onset of underlying issues such as climate change (Haddow et al. 2013).

Future Work

Future output from this study will present refined data visualisations of the framework categories, demonstrating how they change throughout the entirety of the storm season as opposed to subsamples alone. Natural language processing will be used to identify trends in Twitter data relating to the occurrence of hazards in real-life. Disaster life cycle phases for each of the storms will be mapped onto the data to highlight the crossover between events. By focusing on overlapping phases and data from different hazards, contributions to online disaster management strategies may be made by the suggestion of protocols and/or best practices to lesson information overload. Additionally, employing early manual exploration of tweets before beginning data collection should be employed in future events. This will enable Twitter data collection to use varying search terms for collection rather than general terms with the aim to reduce data bias from particular accounts and individuals.

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WhatsApp for Monitoring and Response during Critical Events: Aggie in the Ghana 2016 Election

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ABSTRACT

Mobile Instant Messaging platforms like WhatsApp are becoming increasingly popular. They have expanded access to digital text, audio, picture, and video messaging. Integrating them into existing crisis monitoring and response platforms and workflows can help reach a wider population. This paper describes a first attempt to integrate WhatsApp into Aggie, a social media aggregating and monitoring platform. We report on the deployment of this integration during Ghana's 2016 election, along with Twitter, Facebook, and RSS. The WhatsApp messages collected by Aggie during the election improved the effectiveness of the monitoring efforts. Thanks to these messages, more incidents were found and escalated to the Electoral Commission and security forces. From interviews with people involved in monitoring and response, we found that the WhatsApp integration helped their coordination and monitoring activities.

Keywords

social media analysis, election monitoring, crisis prevention, WhatsApp, Ghana, mobile instant messaging

INTRODUCTION

Since 1992, Ghana has observed free and fair elections every four years, now including three changes of ruling party. Despite a recent history of peaceful and competitive elections, there was still concern that violence could tarnish Ghana's reputation as a stable democracy. In the words of one of our Ghanaian colleagues, "Ghana is seen as a beacon of democracy, and all [of the] eyes on us want to find out what is happening. Can we consolidate our democracy? Can we hold on to what we are known [for]?"

Like Ghana today, Kenya in 2007 "was considered an icon, a bastion of political stability and economic prosperity in Africa." In the 2007 elections, the publication of contested results set off two months of violent conflict across Kenya, in which over 1,000 were killed. "It surprised many that this icon would go up in flames so fast" (Kanyinga 2009).

Goldstein and Rotich (2008) discuss how modern technologies, like SMS (Short Message Service) messages and blogs, were used to promote violence and challenge mainstream media respectively, during the media shutdown that the Kenyan government had imposed during its elections in 2007. In those circumstances, Ushahidi[1] was conceptualized and developed. Ushahidi has since been used for crisis response. It crowdsources, curates, and maps reports from SMS messages, tweets (public posts on Twitter), and its own online platform.

[1]http://www.ushahidi.com

Current research on social media tools for crisis response focuses primarily on Twitter (Imran et al. 2015), but SMS has been widely used. This focus can be partly attributed to Twitter's open API, which lets external applications innovate with few limitations. In contrast, WhatsApp, a leading mobile instant messaging (MIM) platform, does not offer a public open API, complicating programmatic access. Other major MIM platforms offer limited APIs, and some have recently launched public APIs (Rosenberg 2016). Imran et al. (2015) argues the importance of extending crisis response tools to other types of media.

In this paper, we begin the argument that integrating MIM into crisis response tools can reach a broader diversity of users and discover incidents not found on other social media platforms. This paper describes the integration of WhatsApp into Aggie, a social media aggregation platform, during the 2016 Ghanaian elections. After introducing Aggie and the monitoring context, we describe the technical implementation for retrieving messages from WhatsApp. Then, we present an analysis of WhatsApp messages, associated incidents, and interviews with people involved in the monitoring process. Finally, we discuss the challenges of integrating an MIM platform into Aggie and the monitoring process and overview future work.

RELATED WORK

The use of social media in emergencies and crisis response has matured in the last 6 to 7 years (Imran et al. 2015). Several systems have been developed to help emergency response teams detect potential hazards and gain *situational awareness* from information found in social media (Rogstadius et al. 2013). However, most of these systems rely only on tweets, leaving out other major social media and communication channels (e.g., radio, MIM).

Li et al. (2012) mention several reasons behind Twitter's prevalence in systems for detecting incidents: tweets are public by default and Twitter encourages its users to share events in real-time. Combined with Twitter's wide adoption by the general public and the media, many newsworthy events and incidents appear on Twitter shortly after they have happened. In the case of CrisisTracker, Twitter data allows observers to reach places and communities they could otherwise not reach (Rogstadius et al. 2013).

Public broadcasting, e.g. tweeting, is a departure from the uses of traditional mobile communication channels (phone calls and SMS messages). These channels are mostly limited to a single receiver or a limited-size group. Current systems for crisis management and response have mostly ignored these traditional channels. Exceptions are certain crowdsourcing systems, like Ushahidi and Aggie (Smyth et al. 2016) as they have been designed to collect SMS messages with reports of incidents.

Mobile Instant Messaging

MIM platforms have expanded the capabilities of mobile phones. These are platforms which augment the phones' capabilities with instant messages and voice and video calls over the internet. People around the world are increasingly using MIM platforms. Of the top five social media platforms, four of them are MIM platforms with a combined 3.7 billion monthly active users; the leaders are WhatsApp and Facebook Messenger with 1 billion each (Statista 2016).

Church and Oliveira (2013) compare messaging practices on WhatsApp and SMS in Spain. They find that WhatsApp messages "tend to be more social, informal and conversational in nature" than SMS messages. In their research, users felt that WhatsApp was not a substitute for SMS. However, recent trends in Ghana suggest a shift from SMS to MIM. In Ghana, the number of SMS messages sent declined by 25.2% from the second quarter of 2015 to the second quarter of 2016 (National Communications Authority 2016). In the same period, the number of active mobile data subscriptions per person rose from 62.0% to 67.6% (National Communications Authority 2016). In this environment, Ghanaian radio stations, which request contributions from the audience via phone calls and messages, are increasingly using WhatsApp messages instead (Avle 2015).

Previous Uses of MIM in Monitoring and Responding to Crises

MIM systems are now being used by emergency teams to coordinate action response and to receive reports of emergencies. In China, WeChat has been the selected platform by local authorities for reporting emergencies via MIM (Liu et al. 2015). Malik (2016) points to the increased efficiency of a group of engineers reconstructing roads in eastern India due to the use of a closed WhatsApp group. Engineers could quickly communicate with the area responsible with rich messages, and report to the District Magistrate without the need for meetings.

In one of the few analyses of MIM in practice, Debnath et al. (2016) suggests that WhatsApp group chats from emergency response teams can provide a wealth of information regarding the allocation and availability of resources in real time. They analyzed WhatsApp group chats from the NGO "Doctors For You" during two post-disaster scenarios: the Nepal earthquake and the Chennai flood of 2015. They applied simple Natural Language Processing techniques to develop an automated system to look for relevant information in WhatsApp messages and endorsed the aggregation and automatic analysis of the internal messages of multiple agencies.

AGGIE AND THE SOCIAL MEDIA TRACKING CENTER

Aggie[2] is an open source web application for aggregating social media and other digital resources to track incidents around real-time events such as elections or natural disasters. Aggie allows organizations to extract key data from social media posts through automatic aggregation and manual expert filtering. To do so, organizations need to set up a web server with the Aggie application and configure credentials to use the APIs of selected social media.[3]

To aggregate content related to the monitored event, Aggie uses carefully chosen keywords, hashtags, RSS feeds, and public Facebook Pages and Groups. We refer to the posts and messages that Aggie collects as *reports*. Aggie can be used for monitoring any public event harnessing crowdsourced content from social media sources and specialized sources such as ELMO. Collected reports are available in Aggie as shown in Figure 1, a screenshot of the user interface of Aggie. The top bar is a navigation bar, while the second is a live statistics bar. The section below that is the "filter" section, where filters like medium (WhatsApp in this case), keywords, tags, and author can be used to view only relevant reports. Below the filter section is the "reports" section, which contains the latest reports satisfying the filter condition. If no filter is set, all the latest reports are shown here.

Aggie has been designed to work within a Social Media Tracking Center (SMTC) to monitor elections. An SMTC is a group of volunteers who gather and work collaboratively around the clock to monitor social media reports using Aggie during critical events. Generally, an SMTC is organized for an event in advance; this involves recruiting volunteers, identifying sources of reports, and building relationships with partner organizations.

The key teams of the SMTC include the tracking team, the veracity team, the escalation team, and the embedded team. The tracking, veracity, and escalation teams make up the *monitors* of the SMTC and are co-located in a physical space. Additionally, the management team helps with the setup of the SMTC and the institutional collaborations.

The Tracking Team Tracking team members, also called trackers, use filters to read through each report that Aggie aggregates. When they find relevant, actionable reports, they create *incidents*—descriptions of events at a specific time and place—in Aggie.

The Veracity Team The veracity team processes incidents created by the tracking team. They investigate whether the incident is true by requesting additional information from the original source and, simultaneously, attempting to corroborate the incident with traditional media or the embedded team.

The Escalation Team When an incident is verified, the escalation team communicates with the externally located embedded team to provide information to the SMTC's partner organizations. The SMTC may publish fact-checking information regarding escalated incident. Verified incidents that have been sent out in this way are called *escalated*.

The Embedded Team Embeds—members of the embedded team—are members of the SMTC placed in civil organizations or government institutions who pass escalated verified incidents to these organizations and support them in responding suitably and swiftly.

AGGIE AND THE 2016 GHANA ELECTIONS

This section discusses the preparation, implementation, and execution stages of Aggie for the 2016 Ghana elections.

Preparation

In January of 2016, the Executive Director of Pen Plus Bytes[4] got in touch with UNU-CS to request that we use Aggie to support an SMTC during the upcoming 2016 general election. Pen Plus Bytes had previously used Aggie in the SMTC they organized for the 2012 elections in Ghana.[5]

[2]http://getaggie.org
[3]Complete documentation can be found at http://aggie.readthedocs.io
[4]Pen Plus Bytes is a Ghanaian governance, journalism, and ICT civil society organization.
[5]The current director of UNU-CS, Michael Best, led Georgia Tech researchers during the 2012 deployment of Aggie

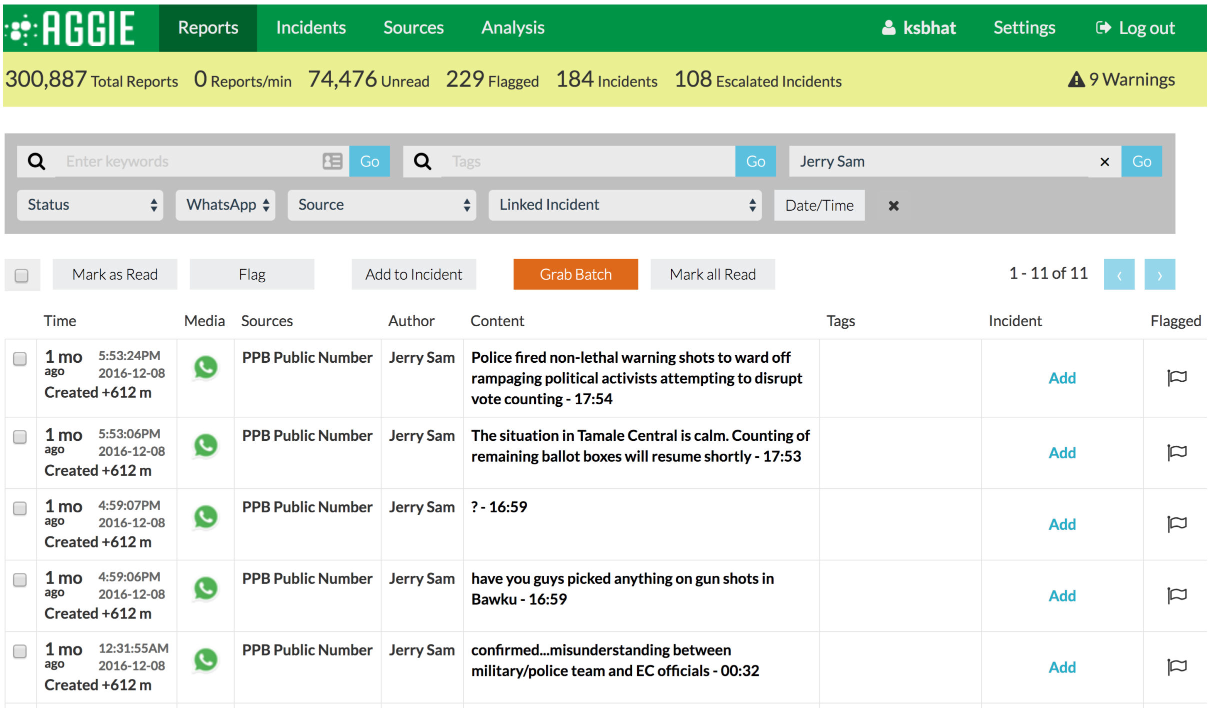

Figure 1. WhatsApp Reports in Aggie

Leading up to the election, we worked with Pen Plus Bytes to design and implement new features for the Aggie software. For Pen Plus Bytes, who served as our experts on the Ghanaian social media landscape, supporting WhatsApp in Aggie was always an interest. Although we had determined that without a public API it would be too difficult to collect messages with Aggie, just before the election the Team Lead—the head of the SMTC—re-emphasized the importance of receiving messages from WhatsApp.

Implementation: Supporting WhatsApp in Aggie and the SMTC

Unlike Facebook and Twitter, WhatsApp has no space for public messages, and WhatsApp does not provide an open interface for logging in and programmatically accessing messages. Aggie's support for WhatsApp, then, is necessarily a *jugaad*[6] implementation—lanky and leaky, but functional.

WhatsApp is primarily an application for mobile devices, but there is an interface for web browsers called WhatsApp Web. When a user is logged in to this web interface and they receive a new message, this web interface sends a desktop notification to the operating system with the author and content of the message. For audio, images, videos, and calls, the content of the desktop notification is text like "Audio (2:21)" and the media file is not included. If the user has a conversation open, however, notifications are not sent for new messages in that conversation. Each WhatsApp account can only be logged in to one browser window at a time.

The Mozilla Firefox plugin *GNotifier*[7] can catch desktop notifications and use a custom command to "display" them. With the SMTC's WhatsApp account logged in to the web client on Firefox, we set GNotifier to forward the desktop notifications to the Aggie server (using cURL). The Aggie server parses the content and author of the message to create reports.

With this setup, Aggie can treat WhatsApp like any other source that creates reports to be read by the tracking team, with little change to the existing workflow and organization of the SMTC. This means it can collect and store WhatsApp messages that have been sent either directly to the SMTC's WhatsApp account, or sent on groups in which the SMTC's WhatsApp account is a member. However, this implementation introduces important technical limitations. For example, if the computer running WhatsApp Web loses internet access or power, Aggie can fail to collect messages from that period.

[6]Hindi word that roughly translates to "hack"
[7]https://addons.mozilla.org/en-US/firefox/addon/gnotifier/

Execution: Running the SMTC with WhatsApp Support

The SMTC began officially (i.e. monitors began tracking, verifying, and escalating incidents) on the morning before the election, December 6th, around 11 A.M., and ended on the evening of the 8th, around 5 P.M. It was managed by a small team of Pen Plus Bytes staff, three researchers from UNU-CS, and one researcher from Georgia Tech.

Prior to the election, Pen Plus Bytes had established rapport with key institutions involved in the elections. Consequently, the SMTC had embeds at the National Election Security Task Force (NESTF) (1), the Coalition of Domestic Election Observers (CODEO) (2), and the Electoral Commission (1). The embeds were either Pen Plus Bytes staff or media experts. The NESTF and the Electoral Commission had set up their own social media monitoring teams to monitor the election. In the case of NESTF, the monitoring team used another Aggie deployment, without support for WhatsApp, provided by a local private contractor.

The SMTC used Twitter and a website[8] to disseminate information about the veracity of incidents, but the website had only 264 unique visitors while the SMTC was operating. And as of 18th January, 2017 the SMTC's handle—@GhanaSMTC—had only 486 followers. In coordination with the SMTC embed, however, the Electoral Commission published tweets (@ECGhanaOfficial, 22.2k followers) which corrected some of the false reports that the SMTC had received.

During the election, the publicly shared WhatsApp account was a member of a set of 35 WhatsApp groups, mostly election-related (exeptions include bible study groups, for instance). The WhatsApp account was added to these closed groups by requesting access from the groups' administrators.

When the SMTC began, the researchers explained to the Team Lead how WhatsApp messages get into Aggie. Because of the risk that leaving a WhatsApp conversation open could prevent Aggie from collecting new messages from that conversation, the Team Lead was clear that access to the laptop running WhatsApp Web should be carefully controlled. It was primarily the Team Lead who responded to conversations on the SMTC's WhatsApp account, and usually only at the prompting of one of the authors.

During the SMTC, monitors created 184 incidents and read 226,405 reports of the 300,517 reports that Aggie collected from four different media. Table 1 links the reports with the incidents.

Table 1. Summary of reports collected by Aggie

Media	Reports Collected	Reports Attached to Incidents (%)
Twitter	249,556	535 (0.21)
Facebook	47,683	27 (0.06)
WhatsApp	2,804	18 (0.64)[9]
RSS	474	4 (0.84)
Total	300,517	584 (0.19)

STATISTICS FROM COLLECTED WHATSAPP REPORTS AND RELATED AGGIE INCIDENTS

The collected WhatsApp reports and the incidents they informed allow us to assess their impact and understand how WhatsApp was used for incident reporting during Ghana's 2016 elections.

Aggie Incidents

After the election 184 incidents were stored in Aggie's database. 15 incidents had WhatsApp messages attached. The Escalated column indicates whether the escalation team took any sort of action on the incident, whether that was publishing information on the SMTC's website or taking the issue to the Electoral Commission or NESTF.

Monitors marked 10 of the 15 incidents as escalated; 5 of the escalated ones were published on the SMTC website. Monitors determined the veracity for 10 of the incidents: 7 true, 3 false.

Of the 15 incidents with WhatsApp reports, 10 were unique; they were exclusively created with WhatsApp reports, and Aggie had no similar incidents. Only 4 incidents were submitted to the WhatsApp account by individuals directly, one of them by an SMTC member. There were 6 different political groups, 3 Ghanaian news groups, and 2 internal SMTC communication groups that contributed reports for incidents.

[8] http://africanelections.org/ghsmtc/

[9] One report was added to an incident by one of the researchers and removed almost immediately, so this has been discounted in the future.

WhatsApp Reports

Table 1 shows that, proportionally, WhatsApp reports were used in incidents more often than posts from Facebook or Twitter. Only RSS posts (collected from five media outlets) outperformed WhatsApp messages on this metric.

To discuss the relevance and potential impact of the WhatsApp reports, we categorized them through manual coding. Test reports (5) were excluded from the coding. The categories for the coding were set up so that the first two, *Actionable* and *Follow-Up to Actionable Reports* would agree with the instructions given to the monitors. Each message was assigned a code by two of the authors. Disagreements between the two codes were resolved through discussion or, occasionally, a decision from the other author. During the coding process, we added and redefined categories; for each of these changes, at least one coder used the updated definitions.

In total, we used ten categories. In the following definitions of the categories, if Category A has *higher precedence* than Category B, reports which would otherwise meet the definitions of both categories are coded as Category A. Most of these decisions about precedence were made because for reports in the higher precedence category it is not practical to determine whether the report meets the definition of the lower precedence category, or because we gave more importance to the higher precedence category for this analysis.

1. **Actionable** Reports that could influence voting or election results (e.g. disenfranchising voters, spreading false news, potential violence) and have sufficient information to act upon.

2. **Follow-Up to Actionable Reports** Reports that provide important information (e.g. location, name, phone number) to support an actionable report (Category 1). This category has a higher precedence than Category 3.

3. **Relevant but not Actionable** Reports that bring information useful for situational awareness around the elections, but do not meet the standard for actionable reports. For the purposes of this definition, we do not consider election results to be "useful."

4. **Conversational** Reports that do not provide much information but are used to establish rapport with the monitoring team. In groups, these are reports that were directed to the SMTC account. (E.g. Asking SMTC for updates, addressing people monitoring the SMTC WhatsApp account.) This category takes precedence over Category 7 and Category 8.

5. **SMTC Internal Communications** Reports that were sent by SMTC staff directly to the SMTC account or that were sent to the Pen Plus Bytes WhatsApp group. Category 5 has been given precedence over all other categories to highlight WhatsApp use by the SMTC.

6. **Election Results** These messages contain information about the polling statistics from different constituencies that people reported, as well as (provisional) results of particular local races. This also included messages informing about concessions, trends, and winners' names in constituencies. Categories 1 and 3 have higher precedence than Category 6; overlapping reports would be those which have some actionable or relevant information in addition to election results.

7. **Other Election-Related** Messages containing election-related conversation, including relevant spam, jokes, and advice, as well as responses to election-related messages—even responses which are not, on their own, related to the election.

8. **Not Related to the Election** Reports gathered by Aggie that are part of different conversations and not related to issues around the election. They can be just propaganda, spam, or reports with little information.

9. **Non-Text** These reports contain no information apart from the kind of media that is sent, e.g. audio, video, photo, etc. Because the audio, video, or photo is not included in the reports, we cannot determine if these fall into any of the categories which require inspecting the content of the message. Thus, this category takes precedence over all others, except for Category 5.

10. **Not Understandable English** Messages written in non-standard English, or are only partially in English where the meaning of the message was lost due to language difference. Messages whose meaning we were unable to determine were classified in this category. If we had been able to understand them, it is possible that the messages could be classified elsewhere, so this category takes precedence over all others, except Category 5 and Category 9.

Table 2. Coded WhatsApp reports

Code assigned	Reports	Reports Added to Incidents
Actionable	39	10
Follow-Up to Actionable Reports	16	1
Relevant but not Actionable	67	2
Conversational	67	0
SMTC Internal Communications	152	3
Election Results	583	0
Other Election-Related	1,292	1
Not Related to the Election	270	0
Non-Text	292	0
Not Understandable English	21	0
Total	2,799	17

Table 2 presents the results of the coding of WhatsApp reports and the number of reports from each category which were added to incidents by monitors.

In addition to the reports added to incidents by the tracking team, we coded 44 messages as *Actionable* or *Follow-Up to Actionable Reports* that could have been added to new or existing incidents but were not. The reasons for their omission are not clear. Perhaps trackers were aware of the incidents described by those messages and had gotten information from other media already. However, it could also be that some of the messages did not provide enough information by themselves for the trackers to considered them actionable; since trackers read reports in batches that collect the latest fifteen unread messages, WhatsApp messages from the same conversation could end up in different batches and be read by different trackers.

The authors of the reports coded as conversational were likely expecting a reply from the SMTC to continue the conversation. Most of these were from individuals, although a few were from groups. Out of 49 conversations with individuals, four resulted in creation of incidents. The 45 others consisted of messages asking for election updates and results.

The content of the reports coded as *Non-Text* were lost for us. Those from individual conversations were still attended to and acted on by the Team Lead when he considered them, but those reports did not end up informing incidents. Trackers did not have a way to evaluate those reports.

Reports belonging to SMTC internal communications consisted of messages sent to two Pen Plus Bytes WhatsApp groups and from two conversations with SMTC staff. Internal communication through WhatsApp resulted in trackers creating three incidents.

INTERVIEWS

As part of a wider research project on the roles of the various media in monitoring the election, we conducted interviews at the SMTC before and after election day. For the purposes of this paper, we have narrowed our analysis to focus on WhatsApp.

Method

Before the election, researchers interviewed three local media experts at the SMTC, one of whom became the SMTC's embed with the Electoral Commission. After the election, the researchers interviewed 17 monitors and the SMTC's four embeds. In addition, the researchers interviewed the three key people at Pen Plus Bytes in charge of running the SMTC.

The interviews were semi-structured and audio-recorded. They typically lasted about 15 minutes for the monitors and 45 minutes for the others. Participants were not compensated; interviews were conducted in English.

The design of the interview for monitors and embeds is based on the *critical incident technique* (Flanagan 1954). Volunteers were asked to retrace the steps they took before critical incidents, i.e., when monitors found actionable reports, or when embeds communicated incidents to institutions. Questions for media experts and the SMTC management team were more general, focusing on their expectations of media impact and its realization.

These interviews were transcribed and the fragments related to WhatsApp were coded for the analysis. The salient themes are aggregated in four main categories: (1) Capabilities of WhatsApp, (2) Technical challenges in using WhatsApp for monitoring, (3) Organizational challenges in using WhatsApp for monitoring, and (4) Impact of using WhatsApp in monitoring.

Results

WhatsApp was a common, often organic, interview topic. Most of the challenges of WhatsApp were discussed by more than one person. Also, the impactful events around WhatsApp were well-remembered by multiple people with different responsibilities, giving a clearer picture of what happened.

Capabilities of WhatsApp

Before the election, the experts were optimistic about the capabilities of WhatsApp, saying that it was easy to use and that it was cheaper than SMS. An expert suggested that since WhatsApp had multimedia support, it would be useful for internal communication and for people to provide evidence with their messages reporting incidents.

When asked about which media would most quickly disseminate news of incidents during the elections, interviewees argued for Twitter, Facebook, and WhatsApp. The Executive Director of Pen Plus Bytes felt most incidents would be discussed first on WhatsApp, given its broad availability. However, he noted that most of those discussions would happen in private conversations and thus not be collected by Aggie: *"WhatsApp is quite widely available, so it means that people can use it quite quickly. The challenge is that we have not figured a way of collecting all this content if they are not in the group. . . or they are not sending us messages."*

The interviewees were mainly concerned with the trustworthiness of the information coming in on WhatsApp. One of the experts explained his fear that fake news could easily jump from digital to physical when, for example, a child tells their parent the fake news they have read in WhatsApp, and parents then spread that in their community. An embed with CODEO said he was double-checking incidents sourced from WhatsApp to ensure that he was not wasting the CODEO volunteers' time.

In apparent contradiction, the NESTF gave more weight to the reports from WhatsApp because they considered them to be unique, according to the SMTC's embed there. One of the monitors summed up, *"In WhatsApp. . . anybody is just sending anything, so you can't really verify. But there's very good information [that] you see [on] WhatsApp. That's why [you] need people on the ground to verify [it]."*

Technical Challenges in using WhatsApp for Monitoring

Many monitors were of the opinion that the number of WhatsApp reports coming in were far fewer than they expected. 2,799 WhatsApp reports were aggregated during the monitoring period.

A major technical issue the monitors talked about was the lack of context in WhatsApp reports on Aggie. WhatsApp is used for either direct conversation between two users, or to converse in groups where multiple people can send messages to each other. Since Aggie presents each message in isolation, it is possible that crucial information was split across messages, and individually, they were incoherent. One interviewee said that WhatsApp messages would be more useful if senders would structure their messages better and include all relevant information in one message.

Organizational Challenges in using WhatsApp for Monitoring

The researchers observed that the lack of a designated WhatsApp monitor was a serious organizational challenge. Because most people at the SMTC had other designated duties, replying to WhatsApp messages was handled by the Team Lead, who already had many responsibilities.

One volunteer said that she was avoiding reading WhatsApp reports because she was not sure how to follow up with them. With sources like Facebook or Twitter, Aggie provides a link to the original report which monitors can visit and use to request additional information from the author. With WhatsApp, however, she had no link to follow, and did not know if she should send a WhatsApp message to the sender personally.

The SMTC's Team Lead felt that two way communication became difficult because there was only one account, and using the device during monitoring would affect Aggie's ability to aggregate WhatsApp messages. Eventually, a second number was used to reply.

The Executive Director of Pen Plus Bytes felt that the use of WhatsApp at the SMTC was uncoordinated: between the SMTC WhatsApp account, SMTC members' personal WhatsApp accounts, multiple Pen Plus Bytes WhatsApp groups, and Aggie, there was confusion over how information should flow.

Impact of using WhatsApp in Monitoring

The Team Lead of the SMTC was positive about the crowdsourcing aspect of spreading WhatsApp messages requesting reports of incidents. He also used the metaphor of the helpdesk to describe interactions where the SMTC gave support to individuals, as opposed to groups of voters.

In one such scenario, a woman contacted the SMTC via WhatsApp, requesting help to vote by proxy. She believed she had met all necessary prerequisites, but the officials at the polling center did not allow her proxy to vote on her behalf. The Team Lead talked to the woman and got in touch with the SMTC's embed at the Electoral Commission. Working with the Electoral Commissioner and the Electoral Commission's Public Relations Officer, the SMTC's embed at the Electoral Commission communicated with the woman and her husband via WhatsApp text messages and calls. Finally, the Electoral Commission's Public Relations Officer took over and resolved the issue with the voter's husband.

The tracker who saw the WhatsApp reports requesting help voting by proxy in Aggie also noted that WhatsApp practices may be more conducive to this helpdesk-style interaction than other platforms: *"a couple other people [were]. . . putting up their own problems in the [WhatsApp] group. And it wasn't more of [a] general thing like how Twitter was."*

The conversational nature of WhatsApp was a relief for verifiers. They were in charge of contacting back the authors of the reports, and noted that WhatsApp users will frequently reply, unlike Twitter users, who will rarely reply back: *"they get into the flow of talking about their problem, it keeps on flowing. Unlike the other [media] where it's more of like a one time [event]—others will retweet, but you're not finding the same person going on and on."*

DISCUSSION

WhatsApp messages improved the monitoring efforts of the SMTC. Ten of the incidents created used information uniquely from WhatsApp, and four of those were escalated. NESTF was clear that they trusted and valued reports from WhatsApp more than those from Twitter or Facebook. The volunteers and staff of Pen Plus Bytes were strongly positive on the importance of getting reports from WhatsApp in Aggie.

The ubiquity of WhatsApp within the SMTC and the ability of Aggie to collect reports from those groups streamlined the workflow of reporting incidents. SMTC staff and collaborators would forward reports and news they gathered independently to the internal communication group or in individual conversations.

The SMTC received significantly more messages from WhatsApp groups than from individual conversations; likewise, most of the actionable reports from WhatsApp were found in groups. Tapping in to existing election-related WhatsApp groups and the communities that use them was important for the SMTC. With a stronger publicity campaign to advertise the WhatsApp account before the election, the SMTC may have seen more individuals reporting to the WhatsApp account.

The impact of the created incidents is difficult to assess, as there is little feedback to the SMTC after incidents are escalated. The severity of the incidents appears to be low, but it is reassuring that the Electoral Commission was informed of the incidents as they were verified.

Unfortunately, even when the SMTC attempted to correct false information they had received in Aggie on the website, their reach was not as wide as hoped. The SMTC published many verified or refuted incidents on their website and in Twitter, but both channels saw low engagement.

Challenges

Although the SMTC was able to use the collected WhatsApp messages with some success, the workflow for WhatsApp messages was hampered by technical and organizational challenges. The addition of WhatsApp to the SMTC brought two kinds of organizational challenges, but they share the same root cause: that WhatsApp is used for a broad diversity of communications. For that reason, sometimes the lines between internal and external communication became blurred.

Integrating any MIM platform into Aggie would likely bring similar challenges; appropriately integrating MIM platforms into Aggie and the SMTC may require a more complex and flexible solution.

Future Work

The results presented here point to possible improvements to the Aggie software to be able to address larger crises with more incidents and more individuals reporting. For example, trackers could benefit from a filter in Aggie to reduce the non-relevant messages they see. In our case 56% of the WhatsApp reports were *Other Election-Related* or *Not Related to the Election*, which did not add information to the monitoring process. Due to the variability of conditions in elections, like monitored region, written language, and local trends, humans would likely still need to take a dominant role in the filtering process. Thus, solutions like supervised machine learning as presented by Link et al. (2016) are promising.

The emergence of chatbots for MIM provides a great opportunity to streamline conversations with individuals providing reports. While there is no support for WhatsApp, chatbots could be implemented in Facebook Messenger or other MIM platforms to guide individuals to give accurate and potentially structured event information. Chatbots could also serve as a preliminary filter for non-reporting conversations.

CONCLUSION

The SMTC in Ghana benefited from Aggie's ability to monitor WhatsApp messages sent to the SMTC's public number: people used the new platform to communicate with the SMTC, and more incidents were created thanks to the information found in WhatsApp reports.

Other social media monitoring tools should consider taking advantage of MIM platforms. Despite the relative ease of using Twitter's API, most of the incidents we found through WhatsApp were unique to WhatsApp. In doing so, organizations using those tools should make concerted efforts to solicit messages from the public, but also to join groups that are relevant to the critical event. Organizations should also consider the recommendations of ICRC et al. (2017) regarding the use of messaging applications for humanitarian purposes.

The technical novelty of this paper is due in part to the fact that WhatsApp does not have an open API. Our implementation can be replicated quickly and has access to group discussions, but with caveats: only textual content is retrieved, and two-way communication is not supported. To overcome these issues, some other MIM platforms provide access to their API, for example through Nexmo.[10] Recently, Facebook Messenger launched a platform for chatbots (Rosenberg 2016) that could serve to gather reports from the public during crises and integrate them in monitoring platforms.

Finally, our coding of the WhatsApp messages should give other practitioners an idea of what sort of messages a MIM system could expect to collect in an election monitoring or crisis response setting.

ACKNOWLEDGMENTS

We would like to thank Pen Plus Bytes for all of their effort organizing the SMTC. We greatly appreciate all the volunteers who gave their time to staffing the SMTC and who participated in this research. Thanks to Ugo Fred, Amanda Meng, Andrew Bayor, Michael Best and Thomas Smyth for their assistance conducting our research. Also, thanks to the reviewers for their helpful feedback on this paper.

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Classifying User Types on Social Media to inform Who-What-Where Coordination during Crisis Response

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ABSTRACT

Timely information is essential for better dynamic situational awareness, which leads to efficient resource planning, coordination, and action. However, given the scale and outreach of social media—a key information sharing platform during crises, diverse types of users participate in discussions during crises, which affect the vetting of information for dynamic situational awareness and response coordination activities. In this paper, we present a user analysis on Twitter during crises for three major user types—*Organization*, *Organization-affiliated* (a person's self-identifying affiliation with an organization in his/her profile), and *Non-affiliated* (person not identifying any affiliation), by first classifying users and then presenting their communication patterns during two recent crises. Our analysis shows distinctive patterns of the three user types for participation and communication on social media during crises. Such a user-centric approach to study information sharing during crisis events can act as a precursor to deeper domain-driven content analysis for response agencies.

Keywords

User Classification, Social Media, Crisis Coordination, Organization, Organization-affiliated.

INTRODUCTION

Social media has empowered citizens to contribute to situational awareness of crisis response teams (Vieweg et al., 2010), who share time-critical observations (Imran et al., 2013) and report needs and offer to help (Purohit et al., 2013), in addition to being instrumental in community healing (Glasgow et al., 2016). Albeit, the consequence of this citizen empowerment has also led to an overload of information, described as big crisis data (Castillo, 2016), which challenges response organizations to leverage citizen-generated data on social media for crisis response coordination (Hiltz and Plotnick, 2013; Whipkey and Verity, 2015). These information filtering challenges align with different aspects of the information coordination for response teams, such as source (*who* shares information), topic (*what* is the information about), and location (*where* is the information shared from).

Prior research in crisis informatics on social media has indeed focused on mining topics and behavior in the content of shared information, studying credibility of information as well as estimating information origin (Imran et al., 2015). The focus of our study is an analysis of the source of information. For improving crisis response coordination, fine-grained understanding of information sources is critical to help improve systematic filtering and vetting of information for trustworthiness (Tapia et al., 2011; Hughes and Chauhan, 2015), such as through detecting on-ground informants (Starbird et al., 2012) or emergent informants (Purohit et al., 2014). Our goal is to focus on automatically detecting organization users, and organization-affiliated users such as traditionally recognized and virtual group volunteers (Reuter et al., 2013), who come forward to help response and relief coordination, however, may or may not be in coordination with each other. This problem is challenging given that most of the social media platforms, especially Twitter in this study, do not provide any field for such user type information in the user profile metadata. However, identifying such user types is essential, given that understanding the dynamics of engagement between emergent organizations and groups during crises (Majchrzak et al., 2007; Opdyke and Javernick-Will, 2014), both governmental and non-governmental stakeholders, is invaluable for improving response coordination, and requires both identification and interaction analysis of user types. The proposed method for automatic identification of user types in real-time can help improve understanding of diverse voices (individuals on behalf of organization and organizations themselves) to assist responding agencies better interact and explore the massive corpus of rapidly generated data on social media, and improve downstream analysis for filtered crowdsourced inputs to aid situational awareness and coordination (Blanchard, Carvin, Whitaker, Fitzgerald, Harman, Humphrey, 2012; Van de Walle, Brugghemans, and Comes, 2016).

We ask the following research questions in this study:

1. Can we classify information sourcing user types in social media communities during crises, i.e. specifically, *Organization, Organization-affiliated* (person identifying affiliation with an organization in his/her profile), *Non-affiliated* (person not identifying any affiliation), and others?
2. What are the patterns of participation of *Organization* user types during crisis responses of two recent events?
3. What are the patterns of content shared by the *Organization*, *Organization-affiliated* and *Non-affiliated* users?

We propose specifically a user classification method using supervised machine learning techniques for assisting rapid social media analytics on information streams of the Twitter microblogging platform, and present an analysis of two recent crises using this method. Our classifier achieved accuracy up to 75% and F1-score up to 71%, where the proposed method exploited user profile information for feature extraction, providing an advantage for real-time analytics to filter continuous information flow for *who*-what-where analysis during crisis responses. The following are examples of *Organization, Organization-affiliated* and *Non-affiliated* users on Twitter in our study, respectively: *a.) The official Twitter account for the American Red Cross, b.) PR Chick, Red Cross Disaster Volunteer, Traveler, Lover of Books, dismal dog trainer of Oscar Wild, and c.) Artist and illustrator, UK based. Digital painting and oil painting. #artist #illustrator #creative #painting #art #Hampshire.*

The proposed technique acts as a precursor for understanding and performing domain-driven analysis of content using domain taxonomies and ontologies of content categorization (Keßler et al., 2013). Responding organizations have increasingly followed keywords during crises and shared content, as well as followed other organizations and individuals on behalf of organizations, although communication of all these users may reflect different behavior as a part of the formal response community. This communication exchange, among responders, organizations and between these entities represent a unique subgroup of the larger corpus of "citizen voices". This subgroup can be inferred to represent a domain driven set of information sources and affiliations as a part of an established community of practice. Organizations also selectively follow specific organizational Twitter accounts with the aim that this trusted set of user accounts are a proxy information source for aligning common purpose-driven information. For instance, NetHope a consortium based NGO that collaborates with over 50 organizations, has a crisis informatics team that follows specific members' Twitter accounts during early phases of a crisis response to improve situational awareness of its members' activities and evolving response needs.[1] The proposed automated technique for source analysis can be used for finding the most informative or significant region-specific organizational user accounts for developing a repository for better future disaster preparedness.

RELATED WORK

Social media platforms have been extensively studied for crisis informatics lately (Imran et al., 2015). One premise described by Zavarella et al. (2014) is the need to transform social media information into a form that can populate existing crisis response knowledge bases, to allow harnessing of social media information into actionable knowledge for response coordination. For that, different kinds of analyses have been performed with a focus on information content and information source to provide some degree of structure to the unstructured data and develop a knowledge base. Primarily, the content-driven analysis of information flowing on social media has been explored extensively for topical and behavioral information extraction, both qualitatively and quantitatively. The dimension of information sources—users, still requires analysis from diverse perspectives.

Among the user analysis for crisis events, prior literature has broadly investigated problems of user influence analysis, patterns of trustworthiness, and onsite versus virtual users. Vieweg et al. (2010) characterized crisis events by different types of information sources who posted messages and contributed towards situational awareness to varied degrees, however, relying on a manual method for user type analysis. Similarly, Olteanu et al. (2015) presented an information source analysis for types of user accounts across several crisis events by

[1] Internal communications with NetHope Crisis Informatics: http://www.thepattersonfoundation.org/blog/the-anatomy-of-an-emergency-nethope-provides-information-to-emergency-responders.html

analyzing manual crowdsourced annotations of users. Among automated methods, Starbird et al. (2012) proposed an automated method to identify on-ground informative Twitter users, while Purohit et al. (2014) proposed a complementary automated method to identify emerging informative users using *who-talks-to-whom* interaction networks. Other approaches (Gupta et al., 2012; Kumar et al., 2013) have proposed methods for identifying community representatives in the network using centrality measures, and a set of *whom-to-follow* based on a user's topical affinity.

In these related approaches for crisis event analysis, the automated identification methods for *Organization* and *Organization-affiliated* user type analysis are lacking despite the recognition among disaster and humanitarian response communities that trusts between individuals and groups – how they share and exchange information – play a large role in coordination activities (Harvard Humanitarian Initiative, 2011; Vinck, 2013). Prior literature on social media analytics in general, non-humanitarian context provides guidance for detecting *Organization* type users on Twitter (De Choudhury et al., 2012; McCorriston et al., 2015; Oentaryo et al., 2015), although not for *Organization-affiliated* user types. We also suspect different communication patterns of *Organization* (or *group)* user types in the humanitarian context, as they are purpose-defined and communicate in a time-intensive environment to deliver response and relief. Foreman et al. (2013) provide a context for the role of emergent collective identity, where user types of *organization* and *organization-affiliated* can be investigated for voicing similar agendas through different channels. Operational use of organizational Twitter accounts (or affiliated individuals) can be inferred as a part of a trusted network of users with common operational interests during a crisis response that is critical to overcoming barriers for response agencies (Hiltz et al., 2014). The identification of such potential user types is essential.

CLASSIFYING USERS BY TYPES

Our goal is to study differences in the patterns of information sourcing and communication by the different types of users, by first automatically classifying them into three key groups of interest, followed by analyzing the content practices of such user type groups. Technically, our problem is a classification problem, where given a user on social media who has posted relevant content about a crisis event, we want to classify whether the user belongs to any of the following user types—*Organization*, *Organization-affiliated*, *Non-affiliated*, and others as *none*. We first describe data sets for our analysis, followed by manual user classification approach, which provided labels for designing an automatic classifier to categorize user types.

Table 1. Seed Keyword Sets for Event Data Collection

Event	Seeds
Matthew	daytona beach storm, daytona beach hurricane, #daytonabeach, #jacksonville, jacksonville storm, jacksonville hurricane, jacksonville rains, cape canaveral storm, cape canaveral hurricane, cape canaveral rains, brunswick storm, brunswick rains, brunswick hurricane, savannah storm, savannah hurricane, savannah rains, myrtle beach storm, georgetown storm, charleston storm, myrtle beach hurricane, georgetown hurricane, charleston hurricane, wilmington storm, wilmington hurricane, wilmington rains, myrtle beach rains, georgetown rains, charleston rains, matthew georgia, hurricane georgia, storm georgia, storm ga, hurricane ga, rains georgia, rains matthew south carolina, hurricane south carolina, storm south carolina, storm ga, hurricane sc, rains sc, carolina rains, carolina storm, carolina hurricane, matthew south carolina, hurricane south carolina, storm north carolina, storm nc, hurricane nc, rains nc
Louisiana	louisiana, baton rouge, louisianaflood, louisianafloods, louisianaflooding, prayforlouisiana

Datasets for Analysis

We collected data for two recent crisis events in 2016 with different scales of geographical impact. The first one is *Hurricane Matthew (Matthew)*—the deadliest hurricane of 2016 that affected over 15 countries including multiple states of United States and resulting in an international response for severely affected counties including Haiti. The second dataset is *Louisiana Floods (Louisiana)*—one of the largest recent natural disasters since Hurricane Sandy in the United States.

For collecting data, we employed a keyword-based crawling approach for English language tweets, which is the most common method for Twitter data studies in the prior literature for event analysis. For collecting relevant Twitter data for an event, we first prepared a seed set of keywords relevant to an event by observing tweets on the Twitter with searches for 'hurricane matthew' and 'louisiana flood' as well as related news articles, in addition to observing top 100 hashtags and terms in the collected data (seed sets provided in Table 1). We then used Twitter Streaming API[2] with 'filter/track' method to collect relevant tweets containing any of the seed keywords in tweet metadata fields[2], such as for a keyword w, it will provide any tweet containing w, #w or W. We stored all the relevant metadata such as tweet text, posting timestamp, tweet type such as retweets, as well as authoring user's self-reported author profile information such as full name, and location.

Manual User Classification

We discuss the crowdsourcing process here first. The annotation task was designed in a crowdsourcing platform—CrowdFlower[3]. Annotators were asked to visit user profiles on Twitter for the sampled set of users, in order to annotate the user type. At least three judgments were taken per sample for the annotation. The job instructions were refined initially with few test users (n=50) until the annotators fully understood the labels and annotated them per our needs (determined by the CrowdFlower platform using proportions of the number of missed judgments to the correct ones). The job instruction to identify the type of user account included a multiple choice single-select question to answer among the following options - a.) *Organization*: if the user profile identifies the Twitter screen-name/handle as an organization or group, such as through a website link to that organization or group, b.) *Organization-affiliated:* if the user looks like a person with an organizational affiliation, where the affiliation must be explicitly mentioned in the user profile (e.g., founder of..., manager at..., working for...), c.) *Non-affiliated*: if the user looks like a citizen, who does not show any organizational affiliations, and d.) *None:* if the user looks like a bot or cannot be determined.

Sampling for User Type Labeling

We select a sample of the data using stratified sampling approach (Nassiuma, 2001) to create a small sample of tweet authors for manual classification via the crowdsourcing task. A total of 1500 unique users were selected from each event dataset. We discarded resulting user annotations with confidence score[4] (platform-provided) less than 60%, to help ensure the quality of manually labeled data for automated classification. The resultant sample size of labeled users for Louisiana event is 1456 and Matthew event is 1472. Table 2 provides the descriptive statistics of our full and labeled dataset.

Table 2. Event Datasets and Labeled Data

Events (2016)	No. of Tweets	No. of Authors	Labeled Users Types			
			Organization	*Organization-affiliated*	*Non-affiliated*	*None*
Louisiana Floods (Aug 14 - Sep 30)	2,884,000	922,010 Labeled Users: 1456	182 12.5%	107 7.3%	1004 68.9%	163 11.1%
Matthew Hurricane (Oct 6 - Nov 30)	3,692,000	1,760,928 Labeled Users: 1472	242 16.4%	129 8.8%	997 67.7%	104 7.0%

Automatic User Classification

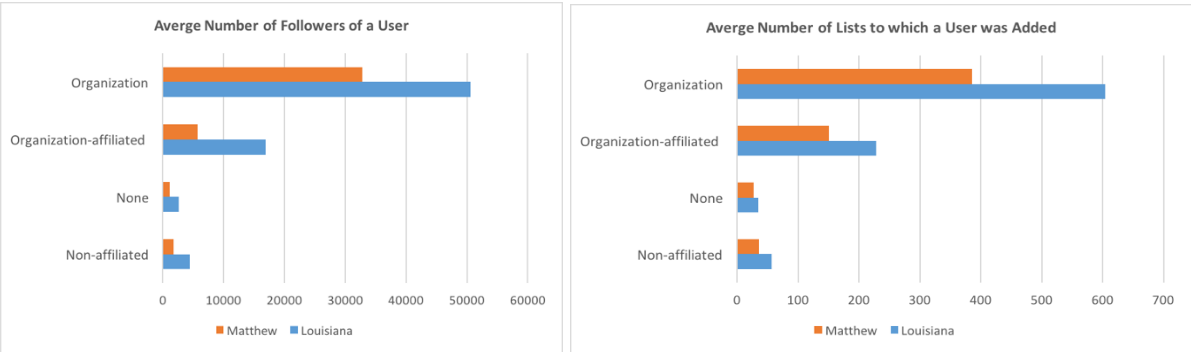
The user classification is done automatically using a classifier trained on the labeled dataset of the manual user classification. The required steps of the automated process consist of basic data preprocessing for acquiring and cleaning the specific metadata associated with users such as profile bio description. This is followed by extracting features from the metadata, such as word frequency in the bio description text. Finally, a supervised classifier is designed based on experimenting with different machine learning algorithms.

Candidate Feature Identification

We explored a variety of user profile metadata for identifying possible feature sets, using the labeled data corpus. Prior research on user modeling on Twitter has used users' social and activity features, such as the

[2] https://dev.twitter.com/streaming/overview/request-parameters#track
[3] https://www.crowdflower.com/
[4] Confidence score describes the level of agreement between multiple contributors (weighted by the contributors' trust scores), and indicates a "confidence" in the validity of the result: https://success.crowdflower.com/hc/en-us/articles/201855939-How-to-Calculate-a-Confidence-Score

number of friends, followers, and statuses. Figure 1a and 1b show the contrast between the distributions of an average number of followers and an average number of lists a user has been added to, for different user types, such as *Organization* versus *Non-affiliated* individual user types. We also exploited the user bio description to create text-based features, which are one of the critical sources of information about the user interest and background. A potentially informative feature for user type is also account status being 'Verified' on Twitter, which is often the case for *Organization* accounts, such as *@RedCross*. However, in our labeled user dataset, we observed that less than 2% of users actually had the 'verified' status, and thus, we did not include it in our potential feature set. It is likely due to the unique crisis context where a diverse range of users participates in the discussion on social media about the evolving situation. Interestingly, we noticed that the majority of organizational users in our labeled user dataset had external URLs in their profiles, linking to their organization's webpages. Thus, we involved this in our feature set as described in the subsequent section.



(1a) **(1b)**

Figure 1. A contrast between the characteristics of user types that informs the feature design of the classifier.

Feature Extraction

The Twitter API provides a diverse set of user metadata attributes, some of which can be leveraged to create features for capturing distinctive characteristics of user type classes. We specifically consider the following feature set for our experimental design:

1. *n-grams* (of user profile description) – unigram (single word), bigrams (a pair of consecutively written words) of the user description text, which provide key details about a user's type, such as *Organization*.
2. *Friends count* – The number of users a user is following, which shows user's interest towards other users, and we anticipate a lesser mean value for *Organization* users.
3. *Followers count* – The number of followers a user has, which shows a user's influence. *Organization* user types are likely to have more followers.
4. *Statuses count* – The number of tweets (including retweets) by a user, which show user activity in general.
5. *Favorites count* – The number of tweets a user has chosen as 'favorite' over time, which shows the user's consistent engagement activity.
6. *Listed count* – The number of public lists a user is a member of, which shows one way to gauge a user's influence degree if others have listed the user in their topical interest lists of followees.
7. *Profile_URL – A* binary feature for the presence or absence of an external URL in the profile metadata, which is often present for *Organization* user types.

For generating *n*-grams features, we first apply the standard text pre-processing steps – lowercasing, tokenization, and stop-words removal on the user description text field, followed by stemming, and transforming a preprocessed text string into *uni*- and *bi*-grams, using the *StringToWordVector* method in Weka[5] tool. The value of an *n*-gram feature is computed using the phrase frequency (*tf*-scoring) (Salton et al., 1975). We select the top 1000 features for the *n*-grams based on *tf*-scoring.

Classifier Algorithm and Results

Using Weka[5] data mining tool, we experimented for the user type classification task. We first explored Random Forest and SimpleCart algorithms that are popular for supervised classification. We further employed an adaptive boosting algorithm – AdaBoost – to improve the classification performance (Witten et al., 2016). These algorithmic approaches have been studied in prior literature for analyzing diverse types of data for classification

[5] http://www.cs.waikato.ac.nz/ml/weka/

problems, where they have performed well. The default parameters are used for the above algorithms in Weka tool. We perform a 10-fold Cross Validation (CV) for reporting robust performance indicators. We use the accuracy (proportion of correctly predicted training samples) and F1-score (harmonic mean of precision and recall, where precision is the ratio of predicted true positives to all predicted positives, and recall is the ratio of predicted true positives to all actual positives) as the performance measures. These are common measures to evaluate the performance for multiclass classification problems.

Table 3. Results for Automatic User Classification, using 10-fold CV (mean Accuracy and F1-score)

Experiment Algorithm	Louisiana		Matthew	
	Accuracy%	**F1-score%**	**Accuracy%**	**F1-score%**
SimpleCart (SC)	72.1	65.0	71.9	66.0
Random Forest (RF)	71.2	67.0	75.1	71.3
AdaBoost with SC	73.2	67.9	72.8	68.5
AdaBoost with RF	73.4	68.5	75.3	70.8

Results are provided in Table 3 that show a range of fair to good performance for accuracy and F1-score measures, with a value of area under the receiver operating characteristic curve up to 0.8 (good discrimination ability). We observed that the overall accuracy near 75% is likely due to the challenge of difficulty in estimating the latent inference of the user type by only user profile information. Although the use of content features from the user's past historical tweets could be useful to further boost performance, our context is particularly crisis situations where there is not enough time to collect historical data of users. We observed that the experiment of boosting algorithm with RF gives a better result than the experiment with SC algorithm for the multiclass case, it is likely because of RF being an ensemble classifier (Witten et al., 2016). We plan to explore the hierarchical classification approach in future studies, given its flexibility to develop an extensible framework for user type analyses, for example, classifying individuals further by demographics of gender.

Table 4. Classified Users in the Pruned Event Datasets across User Types

Types	Classified User Types in Events	
	Louisiana	**Matthew**
Organization	39,718 (6%)	78,809 (6.3%)
Organization-affiliated	11,318 (2%)	25,430 (2%)
Non-affiliated	613,301 (89%)	1,132,208 (90.3%)
None	24,505 (3%)	17,511 (1.4%)

ANALYSIS OF USER TYPES

To study the patterns of communication of the user type categories, we first applied the automatic classifier on a pruned dataset of the complete user set described in Table 2. The motivation for pruning was to only analyze those users and their content practices where the tweet content contained the seed words, unlike any metadata field of the tweet post. Table 4 presents the results for the classified users in the pruned dataset. The majority of the users are individuals with no affiliations reported in their profiles, which may likely be due to self reporting nature of the platform as well as anonymity and privacy concerns. We observe that nearly *6% Organization* user accounts are present in the two events., and only less than 3% (although still substantial numbers due to the scale of the datasets) users actually belong to *Organization-affiliated* user types (e.g., *11k* users for Louisiana event and *25k* users for Matthew event). It can be expected that organization accounts are fewer than individual accounts. Although the importance of such accounts can be generally observed with higher proportion of influence measures in general, for example, by number of followers. An organization account of a responding agency or its affiliated user's account is likely to be followed by many, if they engage on social media during crisis events. For instance, Twitter user account of *American Red Cross* has a number of followers as *3,743,915*.

Content Practices of *Organization*, *Organization-affiliated,* and *Non-affiliated* User Types

We anticipate diverse patterns for the content generation practices by the three types of users in our pruned datasets. In Table 5, we present a comparison between tweets posted by the three key user types, for different characteristics of tweeting practices: number of tweets being *Retweets (forwarding message/post)*, number of tweets being *Reply* or *Mention (referencing another user),* and number of tweets containing *External Links (implying external context linking).* We computed the proportion of each of these characteristics of tweets with respect to the total tweets posted by users of a type class.

Table 5. Comparison of Content Practices in Tweets Posted by the Classified User Types (in Table 4)

User Type	Retweet Proportion		Reply & Mention Proportion		External Links Proportion	
	Louisiana	Matthew	Louisiana	Matthew	Louisiana	Matthew
Organization	21%	22%	7%	8%	72%	62%
Organization-affiliated	46%	61%	11%	10%	67%	59%
Non-affiliated	71%	68%	8%	8%	57%	50%

We made a number of observations from Table 5 for analyzing crisis events effectively, by user types (information source types) in future. For instance, when analyzing the retweeting of a post by an *Organization* or *Organization-affiliated* user than *Non-affiliated* user, higher weight can be associated while vetting the information provided by the message post. Albeit, we are not proposing to completely discard the downstream analysis of the content of *non-affiliated* users independent of user types, which may be important from a perspective of another information source attributes in providing timely situational awareness information.

1. *Organization* users are less likely to *retweet* in contrast to *Non-affiliated* users with highest likelihood, reflecting their type of social media engagement during a crisis as information givers, instead of serving as receivers and propagators. Recent efforts (U.S. Department of Homeland Security, Science and Technology Directorate, Virtual Social Media Working Group, 2013) in the formal response community are starting to find ways for gradually increasing usage of social platforms via *Organization* accounts to source and receive information from citizens, beyond public relations (PR) type of engagement.
2. Both *Organization* and *Organization-affiliated* users are likely to participate in social media conversations with differing degrees. It shows an interesting direction for future analysis of crisis events, in understanding common or conflicting patterns of information sharing for a response *Organization* and its associated *Organization-affiliated* users.
3. We also note that *Organization* and *Organization-affiliated* users use external links in the content of their messages with higher degree than *Non-affiliated* users, which reflects the institutionalized practice of communication with evidence. It presents future study direction to explore the types of URLs shared by such user accounts, in contrast to *Non-affiliated* users. For instance, external URL pointing to information about response and relief versus multimedia content about the situation of affected region and people.

DISCUSSION AND FUTURE WORK

We discuss the lessons, limitations, and future work directions from the presented analysis in this section.

Lessons

We have analyzed the diverse user types participating in social media discussions surrounding real-world crisis events by first identifying such users and then studying patterns of their user-generated content. While proposing a baseline method for user type classification of *Organization*, *Organization-affiliated*, and *Non-affiliated* classes, we achieved a fair to good performance and noted a scope of improvement for both accuracy and F_1-score. Given the complexity of inferring a latent attribute of a user and that also in the context of informal user-generated content practices on social media, we anticipate further exploration to improve contextual features of learning, such as through historic data of users from diverse crisis events.

Limitations and Future Work

We note that our technical problem is a multiclass classification task, which is a more complex task than a binary classification task and has a higher complexity to achieve a better classification performance. However, to scope the study, we did not test different strategies for the efficient classification, such as binarization framework of one-vs-all. Our datasets are available for the research community and will facilitate such future studies. In addition, we explored the natural distribution of the user type classes for training the classifier, which showed an imbalance for user type labels, presenting a challenge for learning an efficient classifier. We did not employ any remedies for imbalance, which again provides a direction for future studies to build on the presented work. The presented analysis only included English language seed terms for collecting data from Twitter API, which provides a place for a multilingual study of events in the future. As a consequence, the percentage of classified users of *Organization* and *Organization-affiliated* types may be an underestimate, given that we were not able to identify users in non-English languages. Such users can be especially important for the events where many affected nations likely have non-English communications on Twitter. Our future work direction is to consider domain-driven content analysis after the precursor analysis of user types, for a better understanding of what information is communicated by which types of users, at a large-scale (given the automated user classifier method). Recent works such as Hodas et al. (2015), have explored the role of domain driven entities, (both experts and lexicon) on improving the automatic extraction of information during crises. In addition, further work is needed to understand what degree of a domain driven filtering process combined with the precursor analysis of user types can improve or provide added value to existing knowledge bases of humanitarian and disaster coordination efforts. For instance, during Hurricane Sandy, Federal Emergency Management Agency (FEMA) and the American Red Cross used Twitter to communicate situational updates, but also followed specific domain driven keywords to explore how it may improve their domain-specific knowledge base for response activities (U.S. Department of Homeland Security, Science and Technology Directorate, Virtual Social Media Working Group, 2013).

CONCLUSION

This study presented a new approach for studying users who engage on social media during crisis events. We specifically developed an automated classifier for classifying users by type - *Organization*, *Organization-affiliated*, and *Non-affiliated*. Our method achieved accuracy up to 75%. We applied this classifier to analyze communication patterns of user types for two recent crises and found diverse patterns of user engagement by the user types. We observed that *Organization* users mainly act as information disseminator than receivers or conversationalists on Twitter during crises, while they could benefit from interacting with and sourcing critical information through other users, including other *Organization* users. For an application, our proposed classification system can be employed for real-time content analysis during future crises, by relying on features of only user profile metadata of the continuous streaming posts.

ACKNOWLEDGMENTS

We thank all reviewers for their valuable comments and suggestions in the two rounds of reviews. Authors would like to also thank Subhankar Ghosh and Prakruthi Karuna at George Mason University, for helping in data collection, annotation, and preliminary analyses of this research.

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Spatiotemporal Dynamics of Public Response to Human-Induced Seismic Perturbations

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ABSTRACT

There is general consensus that subsurface wastewater injections associated with unconventional oil and gas operations are responsible for the rapid increase of earthquake activity in the mid-U.S. Understanding the public response to these earthquakes is crucial for policy decisions that govern developing situational awareness and addressing perceived risks. However, we lack sufficient information on the reactive and recovery response behavior of the public tending to occur in the spatiotemporal vicinity of these events. Here, we review the spatiotemporal distribution of public response to the September 3, 2016, M5.8 earthquake in Pawnee, Oklahoma, USA, via a social media network (Twitter). Our findings highlight a statistically significant correlation between the spatial and temporal distribution of public response; and suggest the possible presence of a spatial distance decay, as well as a temporal far-field effect. Understanding the underlying structure of these correlations is fundamental to establishing deliberate policy decisions and targeted response actions.

Keywords

Crisis informatics, human-induced earthquake, social media networks, spatiotemporal, far-field effect.

INTRODUCTION

Saltwater disposal (SWD) is the process of injecting into deep geologic formations the highly brackish wastewater co-produced during oil and gas recovery. This process has been strongly implicated in dramatically increasing earthquake activity in the central United States since 2009, which is in close proximity to recently developed oil and gas fields (Walsh and Zoback 2015; Weingarten et al. 2015). These seismic events, which are referred to as Injection-Induced Earthquakes (Ellsworth 2013), are frequently collocated with existing SWD wells that are likely responsible for triggering these events (Ellsworth 2013; Weingarten et al. 2015). This phenomenon has led to considerable public concern as well as structural damage (McGarr et al. 2015). Moreover, in 2014, McGarr found an empirical relationship suggesting that the magnitude of an injection-induced earthquake increases with increasing SWD injection volume (McGarr 2014). Consequently, ongoing fluid injection activities in the central United States increase the likelihood of encountering larger magnitude earthquakes and thus the demand for mitigating associated risks escalates. When seeking to mitigate the risks and consequences of human-induced earthquakes and make good policy decisions, it is crucial to have an holistic understanding of the public response to these relatively uncertain events in order to be able to communicate critical information at the time and space of perturbations.

Previous efforts to improve our understanding of the public's response to the increasing frequency of human-induced perturbations has been somewhat limited due to the need to acquire large scale, timely, and location-specific data, along with data on the associated interactions. When spatiotemporally quantifying the occurrence and magnitude of

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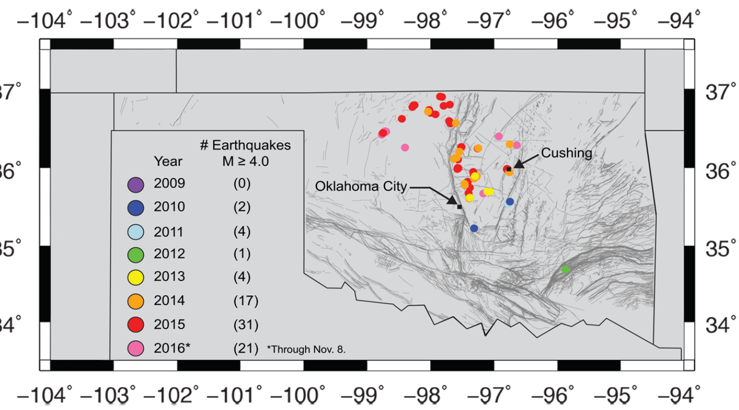

Figure 1. Spatial distribution of M4.0+ earthquakes in Oklahoma from 2009–2016. Earthquake data acquired from the ANSS Composite Catalog (NCEDC, 2014) with underlying fault layer from Marsh and Holland (2016).

public response to human-induced perturbations, one promising approach is to use the rich data available from social media networks. According to an American Red Cross 2012 survey study, 19% of general public relies on social media sites such as Facebook, Twitter and Flicker to seek information in the face of emergency (American Red Cross 2012). Seventy six present (76%) of the general public expected help to arrive within 3 hours and 36% expected help in less than an hour if they posted a request on a social media site (American Red Cross 2012). This study highlights that in emergency situations people tend to both share and seek information to better characterize the event. This implies: 55% of online users would use social media to reassure that they are safe; 55% would share their feeling and emotions about what is happening; 45% would likely share their locations; 42% would share the actions they are taking to stay safe, and 40% would share an eyewitness description of something they experienced. Additionally, 62% would seek information on the damage caused by the event, while 56% would seek the location and status of loved ones; 49% would likely seek information on how others are coping with the situation; 45% would likely look for eyewitness photographs, and 29% for what to do to keep yourself safe (American Red Cross 2012). With this magnitude of public reliance on online resources and social media in emergency situations, it is of utmost importance to better understand the underlying structure and dynamics of this communication system so that the social media platform can be better employed for emergency-related policies and interventions.

In an attempt to understand the interdependencies of the underlying interactions and examine the public responses to location-specific perturbations, a number of scholars have employed geo-social networking media linked to crisis events. A growing body of research is employing social media networks such as Twitter to understand communication typologies and patterns (Bland and Frost 2013; Mohammadi et al. 2016; Sutton, Hansard, et al. 2011; Sutton, Spiro, et al. 2013), crowd behaviors (Lee et al. 2013), information cascades (Wang and Taylor 2014a), disaster responses and crisis management (McClendon and Robinson 2012), as well as sentiment analysis (Caragea et al. 2014) and public responses to extreme events such as hurricanes/typhoons, wildfires, severe storms, flooding, and earthquakes and the resulting changes in movement patterns and population displacements (Wang and Taylor 2014b; Wang and Taylor 2016). Nevertheless, we lack understanding of the spatiotemporal dynamics of the occurrence and magnitude of public response to human-induced seismic perturbations. This becomes even more challenging as these events are different than the natural earthquakes and their subsequent impacts are concentrated in regions where natural earthquakes are unexpected.

Human-induced earthquakes in Oklahoma, USA

Oklahoma is the only U.S. state that has experienced a significant increase in the number of seismic events at all magnitudes over the last 5 years (Walsh and Zoback 2015). Between 1970 and 2009, the annual earthquake rate was 21 per year for M3.0+ events in the central U.S. (Ellsworth 2013); however, Oklahoma experienced 579 M3.0+ earthquakes in 2014, and in 2015 the number of M3.0+ earthquakes increased to 903 (NCEDC 2014). Most notably, the state's level of seismic activity abruptly increased in 2009. Figure 1 shows the spatial distribution and frequency of the state's M4.0+ earthquakes over the eight years from 2009 to 2016 (NCEDC 2014). Many studies have confirmed that the increasing seismicity in Oklahoma is most likely triggered by the considerable increase in SWD activity in this area; the aggregate monthly SWD injection volume nearly doubled from 1997 to 2013 (Walsh and Zoback 2015; Keranen et al. 2013). This is particularly concerning if an induced earthquake aligns along basement faults and thus results in an exceedingly damaging seismic event in an unexpected location.

Here, we investigate the spatiotemporal distribution of the public response to a recent major earthquake near Pawnee, OK, via a social media network (Twitter). The event consisted of a M5.8 earthquake at 12:02:44.400 (UTC) on September 3, 2016. In particular, we examine whether there was a relationship between the spatial and temporal manifestations of the public response and whether the public response decayed with spatial distance from the earthquake's epicenter (36°25′48"N 96°55′55"W) and/or temporal distance from the onset of the event. Put differently, this study seeks to identify the spatiotemporal patterns in public response that form the basis of the popular United States Geological Survey (USGS) "Did You Feel It?" Maps[1].

METHODS

We collected all tweets in the state of Oklahoma that were posted from the onset of the earthquake until approximately 16 hours after the shaking ceased through the public Twitter Stream API[2]. This resulted in over 1,600 geo-located data points (i.e., tweets with geolocation information) for which we extracted those tweets related to the earthquake using a set of keywords such as "earthquake", "quake", and "shake". The extracted tweets were further manually screened to ensure the relevance of the information exchange activities, which resulted in 188 geo-located tweets related to the earthquake. Our dataset included public response measures for 12 time-lapse intervals (i.e., t_1, t_{10}, t_{20}, t_{30}, t_{40}, t_{50}, t_{60}, t_{70}, t_{80}, t_{90}, t_{100}, t_{200}, t_{300}, t_{400}, t_{500}, t_{600}, t_{700}, t_{800}, t_{900}, t_{1000}) from the onset of the earthquake over approximately 16 hours. We then quantified the occurrence and magnitude of this public response in order to capture the spatiotemporal characteristic activity distance.

Public Response Radius of Gyration

We opted to capture the characteristic activity distance of the public response using the public response radius of gyration $r_{g(pr)}(t)$ $(Eq.2)$ as an indicator for the characteristic activity distance of the public response when observed up to time t after the earthquake, which represents the deviation of the $r_{g(pr)}(t)s$ from their corresponding center points $(Eq.1)$. This indicator was then used to track the abundance patterns of the public response over time after the earthquake corresponding to the earthquake's United States Geological Survey (USGS) ShakeMap[3]. We determined the centroid of public responses at each time-lapse interval and calculated the public response radii of gyration accordingly.

$$\vec{p}_c = \frac{1}{n}\sum_{i=1}^{n}\vec{p}_i \tag{1}$$

$$r_{g(pr)}(t) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\vec{p}_i - \vec{p}_c)^2} \tag{2}$$

here, n equals the total number of public response records per time-lapse interval.

We plotted the public response centroids and radii of gyration in the first minute (t_1), the first 10 minutes (t_{10}), the first 100 minutes (t_{100}), and the first 1000 minutes (t_{1000}) and superimposed the results on a map of the region's geological fault lines (Marsh and Holland 2016) to capture the spatiotemporal characteristic activity distance. to capture the spatiotemporal characteristic activity distance. Figure 2 depicts the spatial distribution of these centroids and radii of gyration over the total time frame of the study along with the epicenter of the earthquake. Interestingly, the t_1 tweet occurred outside of the area within which the USGS maps indicated the earthquake was felt, after which the centroids between t_1 to t_{1000} progress towards the epicenter of the earthquake, with the average radius of gyration reaching its greatest extent at t_{10} and then gradually subsiding over the next two time periods.

Distance Decay of Similarity

The results shown in Figure 2 led us to consider two questions: Does the occurrence and magnitude of the public response found in the social media networks exhibit similar distance decay patterns in time and space from the earthquakes' epicenter to those of the seismic wave attenuation revealed in the USGS's ShakeMap and "Did You Feel It Map"(Figure 3)?; If so, does the decay in the public response similarly relate to the degree of proximity to the epicenter and its associated vulnerabilities or is it a far-field effect associated with the structure of such networks, for example population density or social connections?

[1]"Did You Feel It? (DYFI) collects information from people who felt an earthquake and creates maps that show what people experienced and the extent of damage." [https://earthquake.usgs.gov/data/dyfi/]

[2]https://dev.twitter.com/streaming/overview

[3]"ShakeMap is a product of the USGS Earthquake Hazards Program in conjunction with the regional seismic networks. ShakeMaps provide near-real-time maps of ground motion and shaking intensity following significant earthquakes." [https://earthquake.usgs.gov/data/shakemap/]

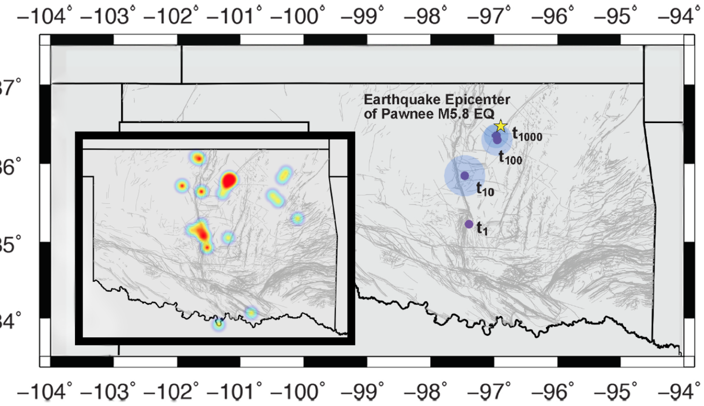

Figure 2. Spatial distribution of public response following the Pawnee, OK M5.8 earthquake, showing the centroid (dark points) and radius of gyration (shaded area around the dark points) for the first minute (t_1), the first 10 minutes (t_{10}), the first 100 minutes (t_{100}), and the first 1000 minutes (t_{1000}) in proportion to one another. The inset heat map aggregates all the spatially distributed geo-tagged social media postings from t_0 to t_{1000}. The underlying fault layer data is from Marsh and Holland (2016).

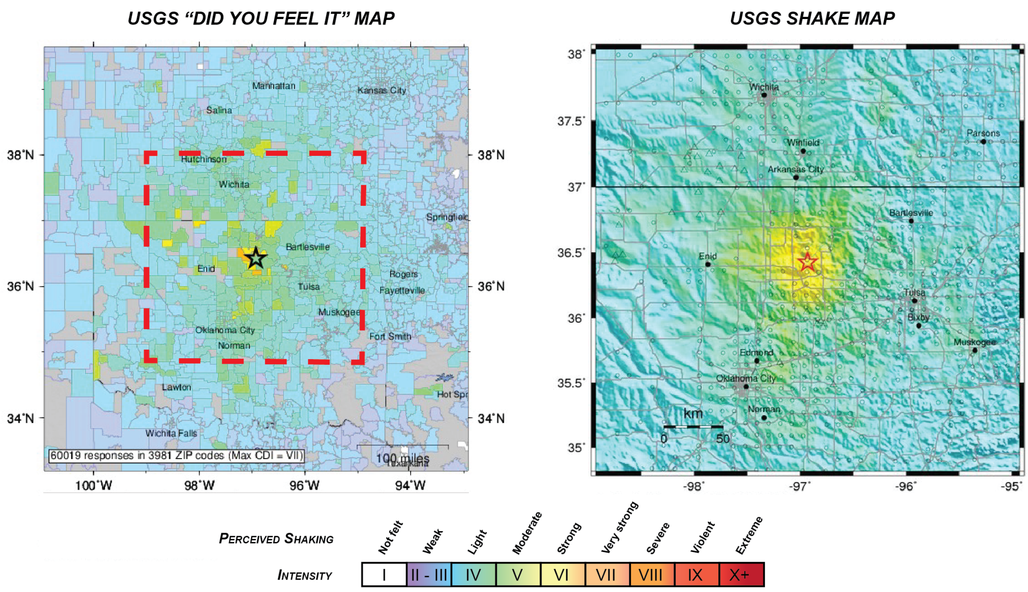

Figure 3. Area of influence for the September 6, 2016, M5.8 earthquake in Pawnee, OK. The earthquake epicenter is denoted as a star in each map. Left panel is the USGS "Did You Feel it" Map, which is compilation of crowd-source data for evaluating the extent of felt seismicity. Right panel is the corresponding USGS ShakeMap reporting earthquake intensity on the basis of ground motions with a categorical scale (I –X+). Area of ShakeMap is denoted as dashed red box in "Did You Feel It" Map. Adapted from USGS (2017).

We applied the Mantel statistic test (Mantel 1953) to examine the relationship between two distance matrices (i.e. spatial and temporal) subjected to a random permutation. The spatial distance for the public responses is measured here by the Euclidean distance between the response centroids and the epicenter of the earthquake against the temporal distance for the magnitude of the public response radius of gyration during the aforementioned time-lapse intervals from the onset of the earthquake (Figure 4(a)). The Mantel test consists of generating two distance matrices: one containing spatial distances between the public response radii of gyration (spatial distance matrix) and one containing distances between the public response radii of gyration at given temporal points (temporal distance matrix). The test consists of calculating the correlation between the two matrices under permutations. The normalized Mantel's test statistic r ($Eq.3$) ranges between (-1, +1) with an r value of 0 indicating no correlation.

$$r = \frac{1}{n-1} \sum_{j=1}^{n} \sum_{i=1}^{n} \frac{(x_{ij} - \bar{x})}{s_x} . \frac{(y_{ij} - \bar{y})}{s_y} \tag{3}$$

where x and y are variables measured at locations i and j, respectively, n represents the number of elements in the distance matrices, and s_x and s_y are the standard deviations for variables x and y, respectively.

FINDINGS

Table 1 shows the result from the Mantel test. Based on these results, we can reject the null hypothesis that spatial and temporal public response, are unrelated with 0.95 percent confidence interval (α = 0.05). The observed correlation, r = 0.4447, suggests that the spatial and temporal matrix entries are relatively strongly positively associated. This indicates that smaller differences in the temporal public responses measures (i.e., public response radii of gyration) are generally seen among pairs of time-lapse intervals that their centroids are more spatially close to each other than far from each other in relation to the epicenter of the earthquake. In fact, the relatively small p-value confirms that the observed relationship between the spatial and temporal distance matrices for public response could have been obtained by any random arrangement in space (or time) in the study area, thus rejecting the null hypothesis that the two matrices are unrelated. Positive values for the normalized Mantel's statistic (r), representing a positive correlation indicate that smaller differences in temporal distance (for example public response radius of gyration at t) are found for pairs that are spatially close to each other in relation to the earthquak's epicenter. This explains why the arbitrary public responses (e.g., t_1) do not belong to a larger neighborhood. However, since the temporal occurrence of the public response has a reverse proximity with the earthquake's epicenter, this suggests that although the abundance and magnitude of the public response decays spatially, it exhibits a counter behavior temporally; as the time distance increases the abundance of public response also increases.

Table 1. Mantel Test between Spatial and Temporal Public Response Distance.

	R	***p*-value**
Mantel Test	0.4447	0.001

Figure 4(b) shows the distribution of Mantel's test statistic (r) from the permutations. It represents the overall significance of the correlation under permutations and can be used to determine the underlying structure of the correlative relationship. Unfilled points represent conditions that are not statistically significant at the specified alpha level.

DISCUSSION

This study is part of an ongoing investigation of the coupled interactions between the public and the growing number of human-induced seismic perturbations in the state of Oklahoma. These events, many of which could result in damaging earthquakes, are increasing in frequency due to the rapid rise in the number of SWD wastewater injection operations in the state in recent years. Developing an holistic and timely appreciation of the location-specific public response to such events is thus crucial. A clear understanding of the spatiotemporal dynamics of the public response aids effective decision-making and the creation of better policies to support both immediate and long-term interventions and care for those affected. This should include, for example, the provision of credible information on the extent of an event, whether the danger has passed, and how officials are responding to secure help. Social media networks such as Twitter are already being employed as a source of situation awareness and public engagement during crisis events, identifying unintended impacts at an early stage and providing timely support to the public. Significant numbers in the general public share and seek information from social media sites

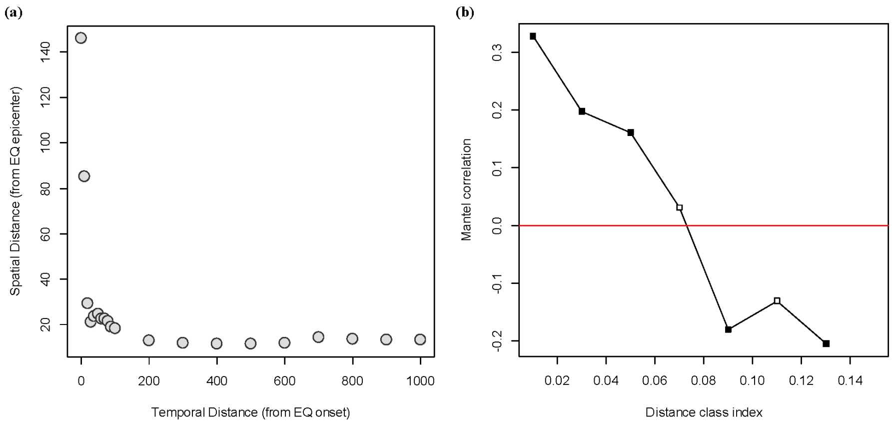

Figure 4. (a) Spatiotemporal distance distribution of public response; (b) Mantel Correlogram.

in the face of emergencies to reassure both themselves and the people in their social network are safe and aware of the situation, the damage caused by the event, and the actions required to be taken (American Red Cross 2012).

Here, we characterized the spatiotemporal dynamics of the public response to a recent human-induced seismic event in the state of Oklahoma, revealing that although the initial response was at a substantial distance from the earthquake's epicenter, the response generally trended spatially towards the epicenter over time. The spatial and temporal occurrence and abundance of the public response were statistically significantly correlated. In the event studied here, there was a reverse relationship between the spatial and temporal decay of the public response with respect to the earthquake's epicenter. Although the abundance of public response decayed as the proximity to the earthquake's epicenter decreased, this measure does not exhibit any decay in behavior as time advances after the onset of the earthquake. This condition could be the aftermath of a possible far-field effect due to an underlying mechanism associated with the social network structure, which allows for temporal proximity to the crisis event despite spatial distance at the onset of the earthquake.

Due to the dynamic and uncertain nature of human-induced earthquakes, it clearly behooves us to study the public response behavior over time and space for a longer period of time and across a wider variety of seismic events (M3.0+ earthquakes) if we are to develop a better understanding of this behavior and its subsequent effects. This ongoing study is expected to continue to observe the social media streams around additional human-induced earthquakes in Oklahoma to characterize the immediate and long-term impact of these seismic events on the public and on individuals. Such study can further facilitate an assessment of how public response behavior changes under repeated disruptions and evaluate how it may evolve in the context of repeated seismic events when faced with different policy interventions. This study represents a first step towards improving our ability to analytically characterize the human system's response to human-induced seismicity and towards developing a better understanding of the overall dynamics of coupled human and natural systems. The results from this study may inform crisis management interventions on the spatiotemporal extent and intensity of public response in relation to the location and intensity of a seismic event.

ACKNOWLEDGMENTS

This study was supported by the National Science Foundation under Grant No. 1142379 [http://www.nsf.gov/]. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Waveform data, metadata, or data products for this study were accessed through the Northern California Earthquake Data Center (NCEDC), [doi:10.7932/NCEDC].

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Interactive Monitoring of Critical Situational Information on Social Media

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ABSTRACT

According to many existing studies, the data available on social media platforms such as Twitter at the onset of a crisis situation could be useful for disaster response and management. However, making sense of this huge data coming at high-rate is still a challenging task for crisis managers. In this work, we present an interactive social media monitoring tool that uses a supervised classification engine and natural language processing techniques to provide a detailed view of an on-going situation. The tool allows users to apply various filtering options using interactive timelines, critical entities, and other logical operators to get quick access to situational information. The evaluation of the tool conducted with crisis managers shows its significance for situational awareness and other crisis management related tasks.

Keywords

Social media, disaster management, information visualization

INTRODUCTION

The role of social networks such as Twitter and Facebook to rapidly monitor different events and activities happening around the world is increasingly acknowledged. During natural or man-made disasters, people use social media platforms to get latest updates about the disaster event, post situational information, report suspicious activities around them, ask for help, and also offer help (Starbird et al. 2010; Cameron et al. 2012; Hughes and Palen 2009). This online information, in the form of textual messages, imagery content, and videos, contains valuable information useful for humanitarian organizations to gain early insights from an on-going situation (Imran, Castillo, Diaz, et al. 2015). If processed timely and effectively, studies have shown the utility of this online content for disaster response and management (Nguyen et al. 2016; Rudra et al. 2016).

Despite its usefulness, consuming and making sense of large amounts of social media content is a challenging task due to a number of reasons. For instance, a big proportion of social media content can be considered as noisy data due to irrelevant and duplicate messages. Many approaches, based on Natural Language Processing (NLP), have been proposed in the past. Despite advances in NLP techniques, automatic classification of tweets to identify their usefulness is still challenging because tweets are short (i.e. 140 characters only), often misspelled, contain slangs, abbreviations, and informal language (Imran, Mitra, et al. 2016). Among others, one effective approach to process tweets is through supervised classification techniques. In this case, a user decides categories of interest to which he/she wants tweets to be assigned to. For instance, such categories could be *report of injured or dead people, urgent needs, missing person, critical infrastructure damage* etc.

However, even if an automatic classification system is in place, making sense of the large amounts of classified messages (several thousand) in each category of interest requires substantial manual efforts. Moreover, if the disaster event spans over days and weeks, this could create a filter-failure issue. To overcome these issues, in this work we propose an interactive monitoring tool to provide rapid access to the most *critical* and *important situational information* during an on-going disaster event. Based on our interactions and learning from many crisis responders, we observe that the most critical information needs of humanitarian organizations or affected people, have certain high-level themes (e.g. categories) and information within each category is centered around some certain entities. For instance, in the case of an earthquake or a typhoon, such critical entities could be the locations where critical

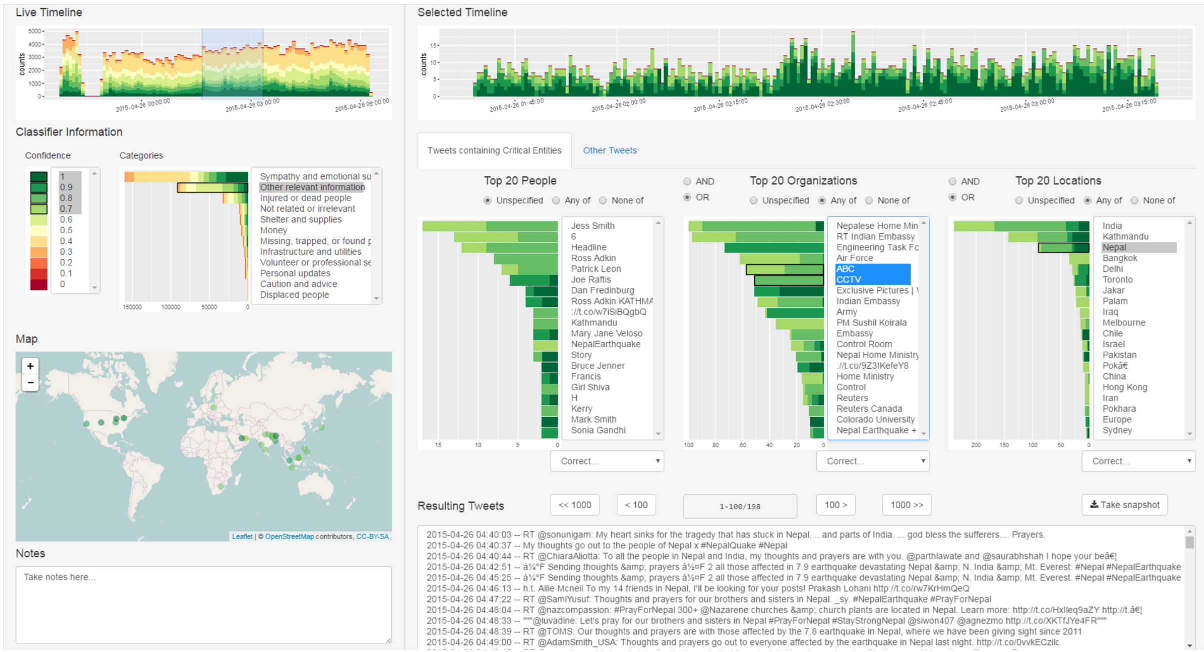

Figure 1. Interactive Monitoring tool full view showing various components like interactive timelines, top entities, map, classifier's options, and filter-view of tweets

infrastructure damage has happened or organizations that are providing aid (e.g. shelter, food, water) to affected people, or names of missing persons, a list of donation providers and so on.

To fulfill such diverse information needs, we employ supervised classification techniques to classify data into different categories of interest of a user. This step filters out irrelevant content. Classified data (i.e., only relevant messages) are then used to extract critical entities using state-of-the-art named-entity recognition techniques. To find most critical entities within each category, we combine our classifiers' classification confidence scores with the proliferation of entities observed over a time-window to fetch top-N most important results. Furthermore, the tool provides an interactive interface to dynamically select a category, a range of confidence scores, and a number of entities to present a filtered view of the messages. Moreover, the tool provides ways to take multiple snapshots of different filtered-views with notes for future reference, which is one of the requirements we learned from crisis managers. Figure 1 shows a full view of the interactive tool. Once the work on this tool is completed, we will make it online at `http://aidr.qcri.org`.

In the sequel, we first present main types of critical information learned from crisis managers. We then describe our interactive tool for rapid monitoring of emergencies. System evaluation details and discussion is presented after that. Related work followed by conclusions and future work directions are presented in the end.

UNDERSTANDING THE TYPES OF CRITICAL INFORMATION

Data, Accessibility, and Interaction with Crisis Managers

People use social media platforms for a variety of purposes. Other than being social and to be in contact with their family and friends, social media platforms, in particular microblogging sites such as Twitter, are ideal to get latest updates on an event. In Twitter, one can search the entire Twitter data repository using simple keywords. Moreover, many social media platforms provide automated ways to consume live information (i.e. real-time access to live posts). For instance, Twitter has a streaming API, which once subscribed using some keywords or hashtags, provides real-time access to posts which match the provided keywords or hashtags.

Such accessibility to live data creates numerous opportunities for humanitarian organizations as well as for affected or concerned people to consume live information during a disaster event. The value of such information becomes more important when no other means of information such as traditional News media, radio etc. are available, which is typically the case in the first few hours of a crisis event. However, not all information on social media is relevant. A big proportion is comprised of irrelevant and duplicate content.

To understand the types of information useful for disaster response and management, we studied the use of our online supervised classification tool (Imran, Castillo, Lucas, et al. 2014). The tool is operational since 2013 and has been used several times by a number of humanitarian organizations such as UN OCHA during a number of major disaster events including disasters such as the 2015 Nepal Earthquake, the 2014 Typhoon Hagupit, and the 2013 Super Typhoon Yolanda. During and after a disaster event, we engage with those humanitarian organizations to get their feedback about the tool.Most of these interactions with crisis managers happen over Skype calls, through emails, or through a post-disaster report that we usually request after a disaster ends.

Based on our interactions, in this section, we summarize our findings regarding different types of information needs of various stakeholders, including crisis managers and individuals who use our platform during disasters. These findings help us understand gaps between the existing features of our technologies and users' information needs. Moreover, it helps determine new requirements for the design of our interactive monitoring tool, which is the contribution of this paper.

High-level Situational Requirements

It has been observed that the information needs of humanitarian organizations vary from one event to another. Past studies attempt to break down these information needs into a set of categories. For instance, Vieweg 2012 presents 28 information categories, while Bruns et al. 2011 report about 13 categories, and Imran, Elbassuoni, et al. 2013 proposes hierarchical categorization consisting of 10 categories. However, we observe an overlap between these categorization schemes. In below, we present a common categorization scheme containing important categories, which we have observed in the majority of the cases during real disasters. Each category is shown with an example tweet from the 2015 Nepal earthquake disaster.

- **Infrastructure and utilities damage:** Reports of damage to critical infrastructure, utilities services, government organizations, communication pools, hospitals, potential shelter houses

  `RT @AshkaITsolution: Nepal's historic Dharahara Tower collapses in massive earthquake: The historic Dharahara tower, a landmark`

- **Missing, trapped, or found people:** Reports of missing, trapped or found people due to the disaster

  `RT @prissy_anne: HELP find my baby sister Ballantyne Forder, she is in Nepal, Kathmandu`

- **Shelter and supplies:** Reports of shelter and supplies requests in different areas and offers of shelter and supplies

  `RT @Gurmeetramrahim: 2day 170 Nepal quake victim families r provided wth tents; relief material - blankets, kitchen commodities, medicines`

- **Injured or dead people:** Reports of affected people due to injuries or dead people

  `More than 900 people dead in #Nepal quake, deadly avalanche on Everest -URL-`

- **Donation of money, food, services:** Requests of donations such as money, food, water, services, blood, and/or offers

  `RT @derasachasauda: Mission NepalDisasterReliefByMSG @Gurmeetramrahim Ji provided relief material; medical aid to earthquake hit Nepal`

Critical Information Centroids

In addition to the high-level situational categorization scheme described above, we observe from our interaction with our users that majority of critical information is centered around certain entities. For example, from disaster response and management point of view, if we closely observe each category mentioned above with the given examples, we clearly see the presence of one or more such entities. For instance, in the case of *Infrastructure and utilities damage* category, the damage is reported to an entity called "`Dharahara Tower`". Similarly, in the case of *Missing, trapped, or found people* category, the report of a missing person including the name of the person "`Ballantyne Forder`" is posted. And, in the case of *Donation of money, food, services* category, an organization is providing relief material and medical aid. These are important reports associated with some entities. However, as it can be seen in the case of the *Shelter and supplies* example, an entity is not always present in each message.

Therefore, rapid access to important entities and the information associated with them is an effective way to quickly filter through large amounts of data during an emergency event. Many crisis managers believe such a functionality

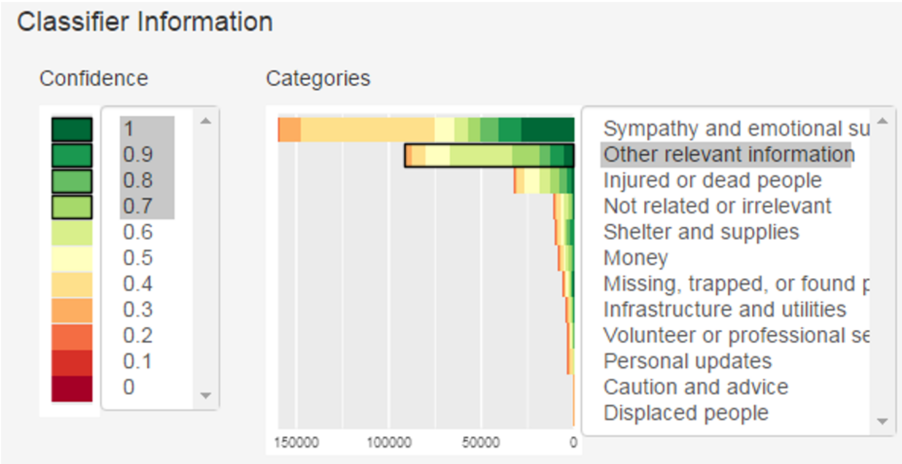

Figure 2. The *Classifier Information* component shows the classifier categories (right bar chart) ordered by decreasing amount of tweets assigned to them, and color-coded classifier confidence score distribution as color segments. The color scale is interactive to filter tweets based on a range of confidence scores, and the user can select the category to focus on. Selected elements appear with a thick black border.

would greatly help analyze crucial information quickly. Moreover, it will also help reduce the burden to go through the remaining situational messages (i.e. reports without entities).

Another requirement we learned from crisis managers is to understand where a piece of information is originated from. For example, this allows identifying the location of the author of a Twitter post. If important reports are put together on a map, collectively, it helps identify big clusters in terms of geographical locations of messages. Obviously, messages posted from a disaster zone would then be given high-priority to analyze and act accordingly. Among other requirements, the ability to interact and apply different filtering criteria, taking snap-shots of the filter-view of data, saving the snapshot with personal notes for future reference, are also considered as requirements for building an effective crisis monitoring tool.

INTERACTIVE MONITORING SYSTEM

To fulfill the requirements gathered from our users (reported in the previous section), we design an interactive tool to monitor Twitter data in real-time. As mentioned earlier, this tool operates on top of our previously built platform (Imran, Castillo, Lucas, et al. 2014), which is responsible for data collection and classification. Before going into the details of our visualization tool, we briefly discuss the data collection and classification parts first.

Data Collection and Building Classifiers

To collect and classify social media data at the onset of a crisis situation, we use our existing AIDR platform. In this paper, we only focus on Twitter data collection, classification, and visualization, so the next discussion will only be on Twitter. At the onset of a crisis, a user defines either a set of keywords/hashtags or a set of geographical bounding boxes or a combination of both. The selected search strategy is used by the system to continuously collect data from Twitter streaming API. A big proportion of social media data may consist of irrelevant information let alone useful for emergency management. To overcome this issue, the user, based on his/her information needs, defines a list of categories to which the incoming tweets will be automatically classified by the system. To enable automatic classification, the user provides a handful of training examples to the system. After one of more classifiers are up, all subsequent tweets are then automatically categorized. Given a tweet, a classifier assigns a category and a classifier confidence score to it. These are the inputs to our interactive tool we present next.

Interactive Monitoring Tool

Figure 1 shows the complete dashboard interface of the proposed tool including its ten important components such as live timeline, top-n entities, maps, classifier scores, tweets view etc. The dashboard mainly consists of two types of components: (i) primary filtering components, (ii) secondary filtering components. The purpose of a primary filtering component is to set high-level filters on large amounts of data to get a focused view. Tweets that pass through high-level filters are displayed on the secondary components. Next, we describe each component in detail. We give details about the graphical design rationale we followed, which are all grounded in the reference books (Munzner 2014) and (Ware 2004).

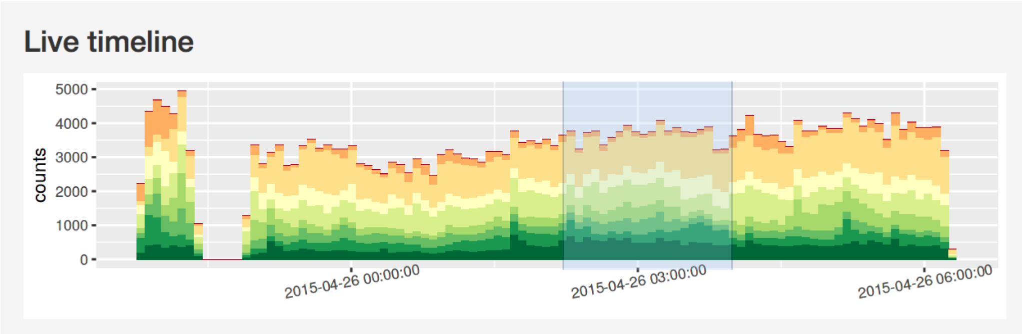

Figure 3. *Live Timeline* component shows beginning to end live timeline of an event. Each bar height codes for a number of tweets collected during a short time period (fixed width of the bar) at a specific date and time. Color segments show the distribution of the classifier confidence scores for this set of tweets.

Primary Filtering Components

There are two primary filtering components on the dashboard: the *Classifier Information* view and the *Live Timeline* view.

Classifier Information View: Confidence Scores and User-defined Categories

As already discussed above, the user defines a set of categories to which the tweets are automatically classified by the system. Each classified tweet gets a category and a classifier confidence/probability score ranging from 0.0 to 1 from the classifier. This score shows the classifier confidence in assigning a category to the tweet. Higher scores (near 1) are preferable and show tweets with desired information. Figure 2 shows the interface for the classifier part.

On the left side, the confidence scores are displayed with a diverging color scale to emphasize good (greenish) and bad (reddish) scores following the green-orange-red traffic-light widespread convention. For instance, the dark green color represents confidence score = 1 and the dark red color represents confidence score = 0. It is important to note that information shown on all other components are based on the classifier confidence scores and associated coloring scheme. A range of scores can also be selected e.g. as shown in Figure 2.

On the right side, we show the list of user-defined categories ordered by their prevalence (i.e. the number of tweets in a category). The length of the bars encodes the prevalence and the classifier confidence score distribution of each category is displayed as color segments for each bar. Greenish colors encode most reliable scores and bars are aligned closer to the vertical reference axis to ease frequency comparison. The bars are presented first on the left as they provide the pre-attentive perceptual information (color, position, and length) that drives the selection of a category. Bars and their category names are aligned on a central vertical axis to ease mutual matching. The user can select one category at a time (e.g. *Other relevant information* is selected in the Figure 2).

The *Classifier information* view is one of the primary filter views on the dashboard. Any selection on this component affects the data shown on all the secondary filtering components. For instance, if a user selects a new category e.g. *Shelter and supplies* then all secondary components will show data from the selected category.

Live Timeline View

To monitor an event at a high-level and to understand how it unfolds, we provide the *Live Timeline* view. Figure 3 shows its interface. This interface depicts the event-level timeline from the beginning of an event to its end (i.e. this could be a view over months of data). On the x-axis, the interface shows date-time and on the y-axis, it shows the frequency of tweets received in a unit time. Each bar contains multiple colors that represent the proportion of tweets classified with a certain confidence score using the same confidence score color-scale as the *Classifier Information* component. The greenish colors bearing the highest confidence levels primarily looked after by users, these segments are aligned with the horizontal reference axis to ease frequency comparison across the timeline.

The timeline is periodically refreshed automatically to continuously update data received since the last refresh. This provides a comprehensive view of how the event is unfolding, how the classifiers are behaving, and what are the distributions of confidence scores. For instance, we can see on Figure 3 that no data have been collected for about half an hour (gap on the left), and that many tweets have a medium or low confidence score. Furthermore, this is our second primary filtering component, that means a selection made on this component affects all secondary views. A user can make a selection of a narrow window-size, as shown with the shaded rectangle area on Figure 3. All the secondary view components will then only show data from the selected time window.

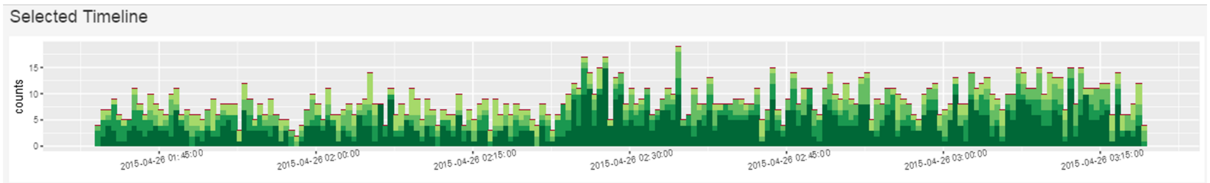

Figure 4. The Selected Timeline component shows a fine-grained view of a filtered timeline of messages

Secondary Filtering Components

As a result of a selection made at any of the primary filtering components, all the secondary components automatically update their view with the selected data (i.e. confidence scores, categories and time window). The purpose of the secondary filtering components is to apply data-driven filters on the selected subset of data obtained from the primary components. For instance, a data-driven filter could be to view all the tweets which talk about a specific location. Next, we describe all of our secondary view components.

Selected Timeline View

The *Selected Timeline* is similar to the *Live Timeline* showing time and tweets frequencies. However, instead of the whole event timeline, it only shows the data within the selected portion of the primary *Live Timeline* component. Hence, the user can have a detailed view of the event from time A to time B. Furthermore, the user can make a further selection on this component to get a more fine-grained focus, in this case, the timeline will automatically update to show only the selected area. As a result of the new selection on this timeline, all the secondary filtering components get updated with the latest information from tweets posted within the selected time window.

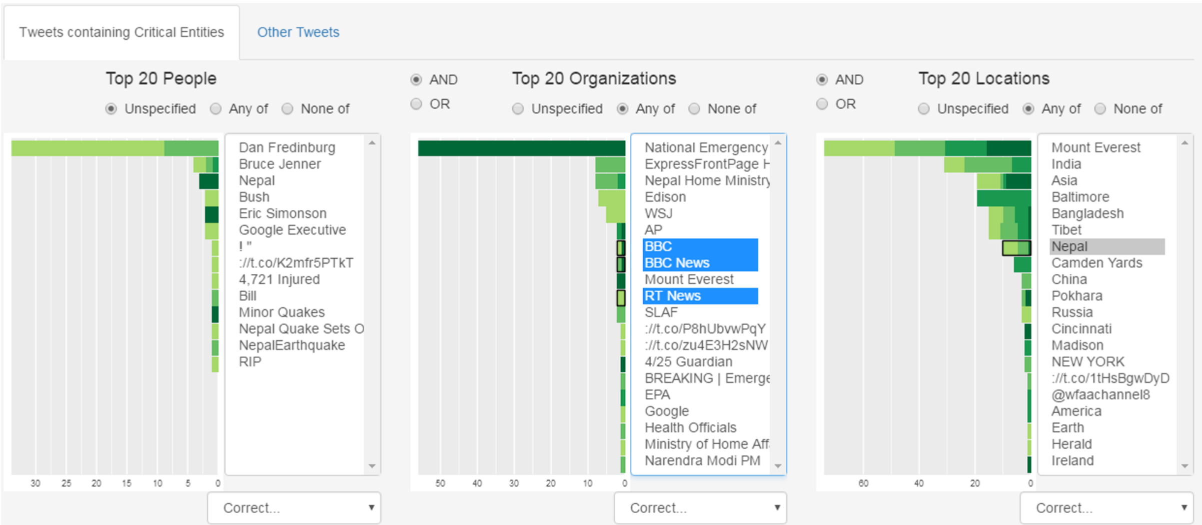

Figure 5. The critical entities component shows three types of named-entities (people, organizations, and locations) along with different filtering options.

Critical Entities View

One of the most important components of our dashboard is the *Critical Entities* view. Figure 5 shows the interface of this component. Based on our findings regarding critical information centroids (presented in the previous section), we extract important entities from the data. For this purpose, we use a state-of-the-art named-entity recognition tool from NLTK[1]. Given a text document (in our case a tweet), the named-entity recognizer extracts entities such as names of persons, organizations, and locations from the text. For each extracted entity, we compute its number of occurrences in the data. We select the top-20 people, organizations, and locations and display them on this component. Each entity is represented by a horizontal bar where each bar shows the distribution of classifier confidence scores along with its frequency. The design of these bar-charts-and-names components and the rationale behind them are identical to that of the one used for category selection in the *Classifier Information* view. Moreover,

[1]http://www.nltk.org/

in this component, we introduce the multi-selection of entities feature (e.g. see the selection of three organizations in the figure 5).

Twitter data are often noisy, e.g. tweets may contain misspellings, shortened words, slangs. Due to such issues, named-entity recognition techniques do not perform well. Often wrong entities are extracted and missed the correct ones. To deal with such issues, we provide a feedback mechanism to allow users to move wrongly categorized entities (e.g. a location name shows up in the organizations) to their correct places. Moreover, entries which are not actual named-entities can also be removed. For this purpose, each entity view has a drop-down menu (see Figure 6) with options to remove or move entities across.

Furthermore, this interface provides a number of filtering options. For instance, one can select one or more entities (e.g. from top people) and select the *Any of* filtering option. This will return a list of tweets in which at least one of the selected entities appears (i.e. logical OR). The *None of* filter will restrict the results to tweets in which none of the selected entities appear (i.e. logical NOT-OR). And the *Unspecified* option is the default to be used when the user does not care about presence or absence of entities of that type in the results. Moreover, one can make a filter across different types of entities. For example, if one wants to see tweets in which a person X and an organization Y appear, then he/she can select the *AND* option which applies between all types of entities at once (both radio button selectors are linked to show the same state). Similarly, the *OR* filtering options can also be applied to all three types of entities.

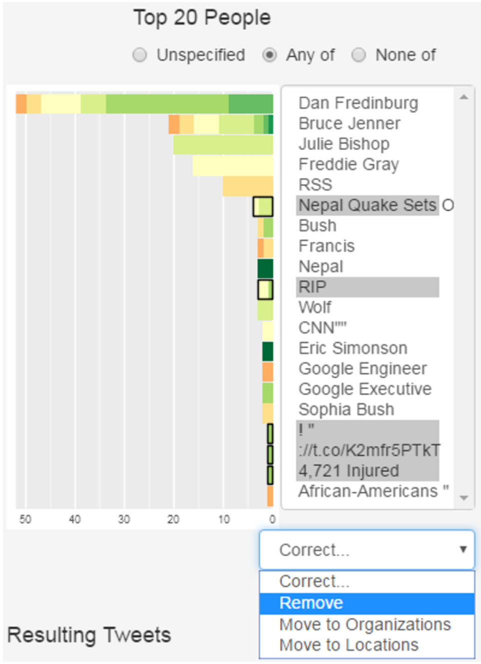

Figure 6. Drop-down menu with options to remove erroneous entities, or to move them to their correct place.

This component alone has the capability to show, for example, what is happening in some locations, names of missing people, or which organizations are taking part in some emergency relief operations and so on.

Map View

One of the most demanded components in our requirement list is the map view component (shown in the Figure 7). Geographically-tagged information is always more informative than a non-geo-tagged information. However, on Twitter only 3% to 5% of the tweets are geo-tagged and the rest remains without any geo information. The map view component simply shows tweets that are geotagged that are selected by the primary filtering components.Each dot on the map is a message (tweet), which can be seen by clicking on it. Each dot on the map has a color representing classifier confidence score and transparency is used to see through multiple dots in crowded areas. The map implements pan and zoom with the top left $+/-$ buttons and the mouse wheel for rapid focus on areas of interest. With this feature, one can immediately get an idea about geo-locations that are producing more relevant data for a given information need.

Resulting Tweets View

The *Resulting Tweets* view is the component where we show the actual tweets as a result of the filter selection made on primary as well as secondary view components (Figure 8). Any filter applied to any other components affects the content of the tweets view. It always shows the updated filtered list of tweets. In this view, we show date and text content of one tweet per row. The tweets are ordered from top to bottom in increasing date and time. The set of tweets is segmented in pages to allow quick navigation through hundreds or thousands of tweets quickly. For this purpose, navigational buttons at the top of the component are used. The total number of tweets found and the range displayed are shown at the top center of the component.

Notes View and Snapshot

Below the map, an editable text area allows the user to take notes on her analysis and findings (see bottom left of figure 1. This feature is useful to take notes on the analysis performed by a user. Moreover, a user can copy-paste tweets by manually selecting them from the *Resulting Tweets* view. When pressed, the *Take snapshot* button on the top right corner of the component allows downloading the data into a text file containing all the resulting

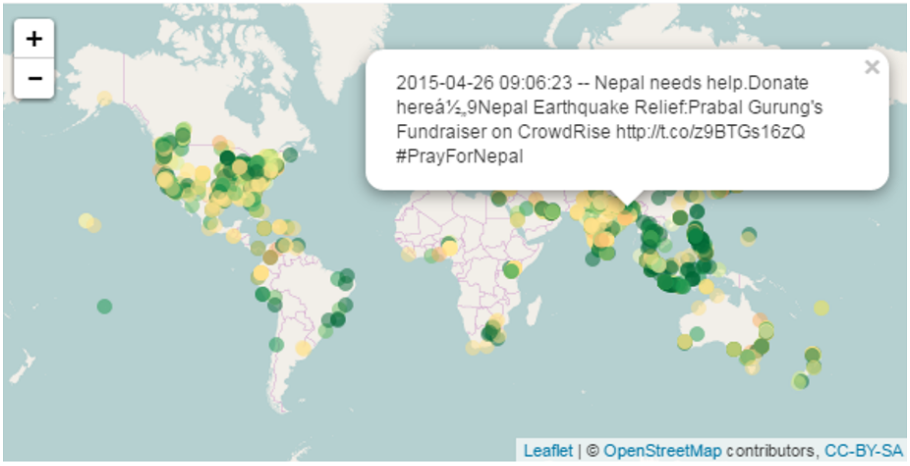

Figure 7. The Map view component show geo-tagged messages

tweets together with a textual description of the boolean filters applied that the user defined through her interactive selections, and the textual content of the *Notes* view. For instance, using this feature a user can create different filters and can save multiple snapshots of the data.

Other Tweets View

Below the *Selected Timeline* secondary filtering component, the user can select either the *Tweets containing Critical Entities* tab or the *Other Tweets* tab. The former shows the *Critical Entities* and resulting tweets containing at least one named entity despite its type or value. The latter shows all the tweets selected from the primary filtering components for which no named entity has been identified automatically. This view is important to keep track of important information without critical entities.

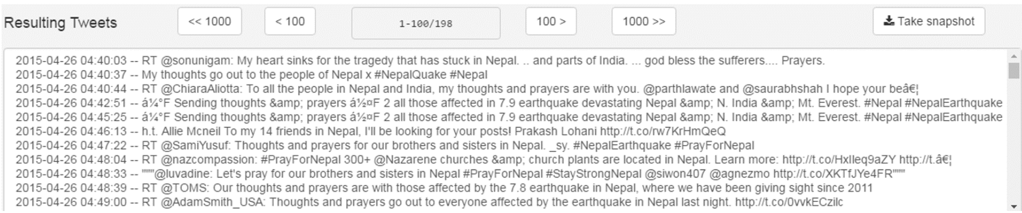

Figure 8. The Resulting Tweets view component shows date, time and text of the tweets resulting from the overall filtering process

USER STUDIES AND EVALUATION

To evaluate the usefulness of our interactive monitoring tool, we interviewed three experienced people A, B, and C who work in the field of crisis response and management. Participants A and B are crisis managers and they work at an emergency management organization in New York, USA. Participant C also closely works with crisis managers and has almost five years of experience building technologies for crisis response and management. For each participant, we first give a general introduction and a live demonstration of the tool showing historical data (the live timeline was static during our demo) from the Nepal Earthquake. Specifically, we use the following demo script.

Demo script

Each interview started with an introduction and motivation behind building the interactive dashboard. Moreover, necessary details regarding our AIDR technology, which is used to classify social media messages, was provided. Next, a demo of the tool including detailed description and functionalities of each component, their interactions, and various filtering options such as entities refinements features, and filtered results analysis are shown. The live demo includes a detailed overview of each component in which selection of different options (e.g. selections on the timeline, changing confidence score ranges etc.). Each demo took 30 minutes on average. We were flexible to change the demo script on participants request. For example, if a participant asked to perform a different filtering option than our planned one, we did so.

Each session has been recorded for a detailed analysis of the discussion that took place during the interviews. After the detailed demo sessions, we asked participants if they had any questions or doubts regarding any component or feature. Each participant asked a few questions. Finally, when participants were satisfied with their understanding of the tool, we asked the following question to each of them.

Evaluation questions

(i) Do you think the tool can help you quickly analyze large amounts of tweets during an event as compared to your earlier approach?
(ii) Do you think the tool can provide a high-level overview of the event as it unfolds using the live timeline and selected timeline?
(iii) Do you think the critical entities we show are good to understand the situation?
(iv) Any suggestions regarding other such entities that we should consider adding?
(v) Do you think the tool can provide a fine-grained view of the critical information (using its critical entities view) from tweets?
(vi) Do you think the primary and secondary filtering component and options are useful and intuitive?
(vii) Is the flow from primary to secondary filtering useful and intuitive?
(viii) Do you think the filtering options on entities components are useful and intuitive?
(ix) Do you think the feature to remove or move a wrong entity is useful?
(x) Do you think the map is a useful component in this context?
(xi) Do you think the notes component and the snapshot features would be useful for you?
(xii) Overall, what is your opinion regarding this dashboard, is it useful for emergency situational awareness?
(xiii) Any other general comments, suggestion, or feedback?

Summary of participants feedback

One general observation we learned is that all the participants look very excited and interested to see the tool. Some initial comments from the participants were "very impressive" (A), "terrific" (B), "great" (C). Participant (A) reminded that a better situational awareness is to understand a situation from different angles, so the map and the timeline components were regarded as very important as they let users catch both temporal and spatial information of an unfolding crisis, and the *Critical Entities* view allows to focus on specific problems concerning population.

Besides the standard pan and zoom of the *Map* and *Timeline* views, the possibility to interactively filter based on categories and on named entities was considered very helpful. (A) liked a lot the interactive color scale to filter tweets by confidence scores of the classifier categories. The *Critical Entities* view attracted most of the interest as it allows the user to design complex filtering rules by simple clicks. (A) and (B) closely examined the top Organizations entities, and told that being able to filter based on these entities would be very useful. For instance, both participants described cases in which it is important to distinguish situations described by official organizations like NGOs or mass media, and also information coming from other sources like people closely involved in the field but with no official role.

The map shows only geo-tagged information and can be used to distinguish people on the crisis site from people in remote locations. However, all the participants wanted to geo-locate all the tweets using the geographical information present in their content. (B) also wondered if a location entity could be automatically breakdown into subdivisions, like a city into its neighborhoods to filter even more precisely. (A) and (B) evoked practical cases in New York where they wish they could use this tool to monitor possible crisis like a hurricane coming to Long Island, based on geographical filtering combined with this named-entities-based filter.

At last all participants questioned the issue of the reliability of the Named Entities and found very useful to be able to clean the set of entities manually when the system makes an error.

Participant (C) is the most technical person among all three. He admired the ability to make corrections of the system through our critical entities view and being able to tune the system while analyzing live data. He also suggested us to map the non-geo-tagged tweets on the map view component. This could be possible by first disambiguating geo-locations and then finding geographical coordinates for tweets mapping. We take this as our future work. Moreover, he suggested us to include a help button with each component so that first-time user can easily understand the system.

Overall, all the participants agreed that the tool helped them analyze large amounts of tweets in timely manner. They found all the components useful and intuitive to use. Overall, all of them seem to like the concept of primary and secondary filtering options that we offer through our components. The notes and snapshot features were considered very useful. Overall, all agreed that such a tool would definitely help crisis managers get early insights from the social media data and ultimately will advance crisis response and management efforts.

RELATED WORK

Dashboards visualize different types of visual components usually containing maps, timelines, and charts in various ways for a broad range of application domains. Some of these tools use social media data for analysis and provide advanced filters. For example, in the crisis response domain, Abel et al. 2012 presents Twitcident, a tool for filtering, searching and analyzing information about incidents that people publish on Twitter. MacEachren et al. 2011 provide a map-based, interactive web application that enables information searching and sense-making using tweets indexing. They display the information based on place and time.

Regarding the design of filters, some works have been proposed to support users to set up a filter based on graphical representations. Kaleidoquery (Murray et al. 2000) is a visual query language to support large data exploration. This language maps SQL statements to graphical elements, providing a visual data navigation technique to select or filter out a subset of the data using a flow-diagram type of graphical representation. Decision trees can also be used to represent filtering of a data stream (Elzen and Wijk 2011; Gangavarapu et al. 2016). In these approaches, a tree represents a filter that is applied to the data passing from the root to the leaves. While decision trees are useful to visualize the data filtered at each level they spend unnecessary space to represent the tree structure at the expense of the details of the filters encoded at each node. VizFilt is another approach designed for the analysis of data streams in the cyber security domain (Aupetit et al. 2016). It uses a bar chart representing a filter where bars both encode the items of the filter and the amount of data filtered by these items in a very compact way. The problem is that these bars are not visually linked to the categorical values they encode (IP addresses, source and destination ports, countries) other than using a discrete color scale. In our case linking such bars to the critical entities (people, organizations or location) help select most important entities easily. So, we propose a similar approach but with grouped bars instead of stacked bars.

A dashboard of the data stream from social media called NStreamAware has been proposed in (Fischer and Keim 2014) to gain situational awareness in the cyber-security domain, but it is applicable to other domains as well. It focuses on extracting relevant features and visualizing time slices from a stream of network data. Word clouds and node-link diagrams are the main graphical metaphors used to visualize network information of interest. However, this tool does not provide quantitative indicators like bar graphs to support the user to include entities of interest in a filter or to let her know the confidence score of the automatically clustered entities. It does not allow for correction of the erroneous classifications either.

A haze monitoring system[2] centered on a map component and information from social media (Pulse 2016). Timelines and filtering components based on critical entities are displayed in a dedicated "Analysis of user generated content" panel. However this information is static, they are not linked to the map or the timeline. No confidence score of the keywords and categories like "Haze Health" or "Haze Impact" is visualized and it does not allow interactive filtering of messages related to specific keywords nor to see the messages themselves to get the context where these keywords were used.

CONCLUSION

Information available on social media platform during an emergency situation proved to be useful for crisis response and management. However, analyzing large amounts of social media data pose serious challenges to crisis managers, especially under time-critical situations. Even if a supervised classification approach is employed, analyzing thousands of machine-classified messages is a non-trivial task. In this paper, we presented an interactive tool to effectively monitor social media big crisis data in a timely manner. The tool provides a number of useful components to gain early insights by applying various filtering options. The interactive timelines provide both coarse-grained and fine-grained view of the event, and the critical entities filter allows detecting relevant entities that are being reported in a given time-window. Evaluation performed with experienced crisis managers demonstrated the significance of the tool.

Future work: Based on the feedback obtained through users interviews, we aim to improve the interface by including the map in the filtering process and to display both geo-tagged as well as geo-coded tweets for which geo-location can be inferred from the content of a Twitter message. We aim to cluster related tweets and entities to ease the selection and filtering of tweets. Moreover, we aim to improve the performance of the classifiers by employing feedback mechanism from users. This will not only improve the named-entity recognition system, but also the automatic classifiers that categorize tweets into different humanitarian categories.

[2]http://hazegazer.org/home

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User-Assisted Information Extraction from Twitter During Emergencies

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ABSTRACT

Disasters and emergencies bring uncertain situations. People involved in such situations look for quick answers to their rapid queries. Moreover, humanitarian organizations look for situational awareness information to launch relief operations. Existing studies show the usefulness of social media content during crisis situations. However, despite advances in information retrieval and text processing techniques, access to relevant information on Twitter is still a challenging task. In this paper, we propose a novel approach to provide timely access to the relevant information on Twitter. Specifically, we employee Word2vec embeddings to expand initial users queries and based on a relevance feedback mechanism we retrieve relevant messages on Twitter in real-time. Initial experiments and user studies performed using a real world disaster dataset show the significance of the proposed approach.

Keywords

social media, disaster response, query expansion, supervised learning

INTRODUCTION

The adaptation of microblogging platforms such as Twitter during crises, emergencies, and time-critical events has increased recently. Easy access to social networks provides ways to produce and retrieve information in different forms, such as textual messages, images, and videos. For instance, at the onset of a crisis event, people use social media platforms to fulfill their quick information needs. Access to critical information becomes more important, especially in the first few hours, when no other information sources such as, traditional media, news channels. are available. Moreover, rapid access to important information can help humanitarian organizations gain situational awareness, early decision-making, and to launch relief efforts accordingly.

Past studies have shown the presence of various types of important information on social networks (Hughes and Palen 2009; Starbird et al. 2010; Imran, Castillo, Diaz, et al. 2015). For instance, this includes information about critical infrastructure damage, reports of injured or dead people, urgent needs of those affected, reports of missing people, donation requests or offers and so on. Moreover, studies have shown the usefulness of such online information for disaster response and management. However, filtering a deluge of noisy information during an event to retrieve relevant information is a non-trivial task. Different approaches based on automatic, crowdsourcing, or combination of both have been proposed to process social media content during an event. For instance, Artificial Intelligence for Disaster Response (AIDR) (Imran, Castillo, Lucas, et al. 2014) is one such application that uses supervised classification techniques to process millions of messages posted on Twitter. However, training supervised machine learning classifiers at the onset of an event requires human-labeled data. Obtaining human-labeled data in the early hours can be done either via paid crowdsourcing (e.g. using CrowdFlower[1] or Amazon Mechanical

[1] http://crowdflower.com/

Turk[2]) or by employing volunteers. In either case, one has to pay a cost, which is *monetary* in the case of paid crowdsourcing and *time* in the case of volunteers. Ultimately, the scarcity of labeled data pose challenges for machine training and consequently it delays the processing of important information for end-users.

While obtaining labeled data is a time consuming task, but at times of a crisis there are usually abundant unlabeled data. For example, during the 2012 Sandy hurricane, the highest peak observed was around 16k tweets/min posted on Twitter. Given, we have no labeled data but access to thousands of unlabeled tweets in the first few hours when a disaster occurs, in this work, we aim to achieve the following two objectives:

(i) To fulfill end-users' critical information needs at the onset of a crisis situation when training a supervised classification system is impossible due to the scarcity of labeled data.

(ii) While fulfilling users' information needs, the second objective is to train a supervised classification system as quickly as possible to enable automatic prediction of new tweets.

To meet the above two goals, in this work, we propose a novel approach that utilizes state-of-the-art techniques from both unsupervised and supervised machine learning fields. Specifically, for the first task, we use a special form of word representation, called "word embeddings". We use the word2vec implementation from Mikolov et al. 2013 and train our own word2vec model using crisis-related tweets collected during a real disaster event. Given a user query, which usually consists of three to five words, we use the trained word2vec model to expand the original query terms using an automatic query expansion technique. The query expansion concept has a long history in information retrieval and has been applied in a number of contexts and application areas of information retrieval (Carpineto and Romano 2012). Basically, for each term in the query, we find top-n contextually similar words that we learn from a large corpus. The expanded query is then used to retrieve top-n tweets that have high similarity with the query vector. Moreover, we optimize the initial query. To get an optimal query vector, which can increase the retrieval of relevant tweets, we use the Rocchio algorithm (Joachims 1996).

To achieve the second objective, that is to train a machine learning classifier while retrieving relevant documents to fulfill the user's information needs, we adapt a relevancy feedback mechanism to get user's feedback on query results. In a relevance feedback technique, users of a system are involved in the retrieval process to improve the system's ability to fetch relevant results over time (Ghorab et al. 2013). In our case, the user provides feedback whether a returned result is relevant or not. We not only use this feedback to optimize the query vector, but also consider it as gold standard labels. That means, user's agreement on items relevancy is used to label those items accordingly. Upon collecting a handful of such labeled examples, we train a supervised machine learning classifier. Subsequent relevancy prediction is then performed by the trained model. The relevancy feedback mechanism continuously runs and keeps improving the classification performance. The results obtained from the experiments and user studies show the significance of the proposed approach. Once deployed, people in the crisis zone, affected communities, and crisis managers will be the users of this system.

The rest of the paper is organized as follows. In the next section, we provide detailed description of our proposed approach. Details regarding datasets and experiments are provided in the dataset and experiment section. Next, we summarize related work and conclude the paper in the last section.

PROPOSED APPROACH

To retrieve relevant tweets against a user query during an on-going crisis event, we propose an approach which mainly consists of two major computational components. The first component responsible for query expansion and fetching of relevant tweets, whereas the second component implements the relevance feedback mechanism and query optimization. Before we get into the details of the system, we formally define our task as follows:

Given a query q and a large set of unlabeled tweets T_{ul}, our task is two-fold: (i) to fetch the most relevant tweets T_r from the unlabeled tweets set T_{ul} by expending the query q using an already trained word embedding model (Let U be an $|V| * k$ term embeddings matrix); (ii) given a training data (x_i, y_i), where $x_i \in X$ and $y_i \in (1, ..., K)$ class labels (in our case two labels), train a machine learning predictor $f : X \rightarrow Y$, where X is the set of documents (tweets in our case) that we want to label to one of the Y labels.

Figure 1 shows the high-level pipeline of our system. The system receives a query from the user. In our case, a query usually consists of three to five words, e.g., "reports of inured or dead people". A straight-forward approach to get related tweets is to run a similarity (e.g., cosine similarity function) between a query and unlabeled tweets. Due to limited context given in such short queries, the coverage of the returned results will be very low thus the retrieved documents will either be too few or irrelevant. To resolve this issue, we expand the context of the query.

[2]http://mturk.com/

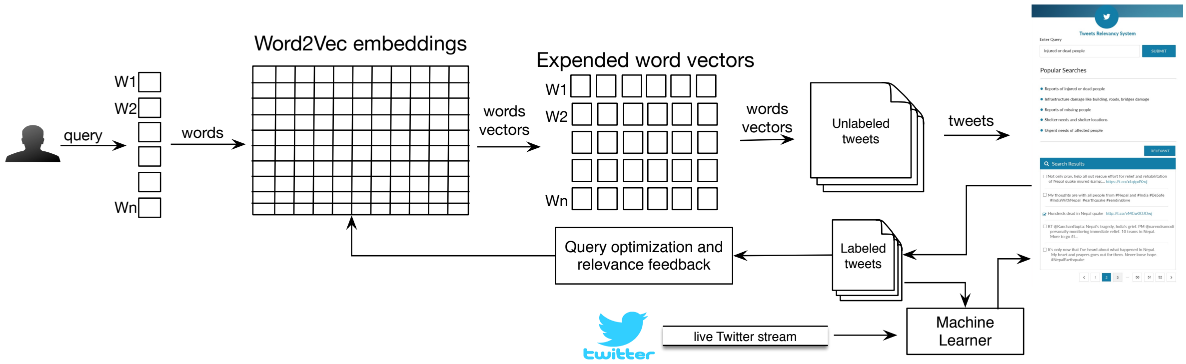

Figure 1. Query expansion and relevance feedback pipeline to retrieve relevant tweets and machine training

For this purpose, we use a state-of-the-art recent approach for word representation known as "word embeddings". Mikolov et al. 2013 proposes two different models (CBOW and skip-gram). In this work, we use the skip-gram model, which given a large corpus of text it learns the proportions of word occurrences and their context (e.g., five words before and after a target word). So, then given a window size n, words around a target word w, the skip-gram model predicts the neighboring words.

We trained a skip-gram based word2vec model using approximately 1200k crisis tweets with vocabulary $v = 108,025$ along 300 dimensions using a window size $n = 3$. We used the 2015 Nepal earthquake crisis-related tweets from CrisisNLP (Imran, Mitra, and Castillo 2016). The trained model is then used for query expansion. From the user query, we first remove stop words if any and then get top-20 highly contextually/semantically similar words from the trained word2vec model. Each query word is expended along 20 contextually similar dimensions. In figure 1, we show this representation under expended word vectors.

The original query words along with expended word vectors are then used to retrieve high similar tweets from the unlabeled tweets corpus. Specifically, we first take an average over the expended words vectors and then by using cosine-similarity measure we fetch top-20 most similar tweets. The retrieved tweets are then presented to the user. The user examines the tweets and mark the ones which he/she thinks are relevant to the original query. The user annotation/marking procedure divides the result set into two sets (i) relevant set (i.e., the tweets the users marked as relevant), (ii) irrelevant set (i.e., the remaining tweets the user did not mark).

Now, given the two sets of tweets from users (relevant and irrelevant), we aim to optimize the expended query vector so to get good results during the next iteration. For this purpose we use the Rocchio algorithm (Joachims 1996), according to which the optimal query vector is the one that maximizes similarity to relevant documents while minimizing similarity to irrelevant documents. Formally, it can be defined as:

$$Q_{opt} = argmax[sim(Q_{org}, D_r) - sim(Q_{org}, D_{nr})]$$

where:

Q_{opt} represents optimal query vector
Q_{org} represents original query vector
D_r represents relevant documents
$D_n r$ represents non-relevant documents

Using the relevance feedback mechanism, the optimal query optimization runs until it converges (i.e. an optimal query is obtained). The number of iterations required to get an optimal query depends on a number of factors. For instance, the complexity of the query (simple or complex queries) or on the length of the query (short or long). All such factors effect the overall retrieval procedure and the time to get an optimal query.

While running the relevance feedback and performing the query based tweets retrieval, we keep track of the labeled tweets. Once a handful of labeled tweets are collected, in our case 50 tweets in each category, the machine learner trains a relevancy classifier. We treat this as a two class classification problem i.e. relevant and irrelevant. In this case, the relevant class represents the tweets relevant to the user query, which are marked by the user itself. As our learning scheme, we use Random Forest with 100 trees. The model is trained using uni-gram and bi-gram based features extracted from both the relevant and irrelevant sets and we select top 1k most informative features.

The model evaluation is performed using 10-fold cross-validation technique. Evaluation results from various experiments are presented in the next section.

Once a model is trained, automatic categorization of subsequent tweets from Twitter live stream starts. The user seamlessly start receiving tweets categorized by the classifier. At this point, the query based tweets retrieval procedure stops. However, the feedback mechanism can still be running. But, now the user feedback is used to improve the existing trained model instead of query optimization. We train new models upon receiving a batch consisting of 50 labeled tweets. We recommend users to frequently mark results (relevant or irrelevant), when they observe high misclassification from the system.

DATASET AND EXPERIMENTS

We use the 2015 Nepal earthquake data from CrisisNLP (Imran, Mitra, and Castillo 2016). The dataset was collected from the Twitter streaming API using different keywords and hashtags during the disaster. In our case, we use around 1,200k unlabeled data. Before training the word2vec model and classifiers, we perform data pre-processing. Specifically, we change tweets to lower case, remove links, stop words, mentions, RT words, special characters, and extra spaces. We used the following five queries to retrieve the relevant tweets using our query expansion and optimization techniques.

(i) Reports of injured or dead people
(ii) Infrastructure damage like building, roads, bridges damage
(iii) Reports of missing people
(iv) Shelter needs and shelter locations
(v) Urgent needs of affected people

In below, we show a list of top five tweets retrieved by our system for each query after query optimization.

Reports of injured or dead people

T1: `News1130radio: Hundreds confirmed dead after massive #earthquake in #Nepal URL`
T2: `Massive 7.9 magnitude earthquake strikes Nepal, 108 feared dead`
T3: `#BreakingNews Death toll from Nepal quake nears 2,000 URL`
T4: `My heart is with those affected by this powerful quake. 7.8 Earthquake in Nepal Kills Hundreds, Levels Buildings`
T5: `abcnews: Nepal Quake: search for survivors, with 50 people missing in Dharahara Tower collapse URLs`

Infrastructure damage like building, roads, bridges damage

T1: `Several buildings including ancient temples collapse in Kathmandu after magnitude 7.9 quake URL`
T2: `Nepal's earthquake damaged a 19th century building. Sad. #NepalEarthquake`
T3: `More than 6.6 mil people in the area affected by #Nepalquake. Widespread damage and destruction of infrastructure feared`
T4: `Buildings Are Down And Roads Are Out After Major Nepal Earthquake, Cnn Sister Network Cnn-Ibn A powerful`
T5: `monuments decimated, roads and bridges destroyed, electricity out and general chaos #Nepal needs the world's support`

Reports of missing people

T1: `Rescue teams raise efforts on mount Everest to search for missing climbers, 30 climbers are injured, rescue continues..`
T2: `googleindia: We've just launched a Person Finder instance to help track missing persons for the #Nepal earthquake`
T3: `pray for nepal, everest.. avalanche, hikers are missing`
T4: `Trekkers reported a major avalanche on Mount Everest, with some teams reported missing.URL`
T5: `Nearly 700 people known dead, many more missing under rubble, as Mag 7.8 #Earthquake hits near #Kathmandu..`

Shelter needs and shelter locations

T1: `Stay strong Nepal. #Kathmanduquake. Send people to these shelters closest to you. URLs`
T2: `RT sarojdhakal: Make your shelter and help build others #NepalEarthquake #earthquake URL`
T3: `PLAN staff reporting collapsed and damaged buildings in Kathmandu. Shelter needed as buildings unsafe #NepalQuake`
T4: `Major aftershock hits Nepal after earthquake Habitat for Humanity mobilizing to assist with shelter needs`
T5: `brick school being used as shelter for villagers who've lost homes #NepalQuake #Wales #par`

Urgent needs of affected people

T1: `The Govt. and people of kathmandu urgent need the medicine supply and small scale mchines tools for removing collapsed building.`
T2: `RT CHOICEorg: We are encouraging #donations that will be directed to the most urgent needs of #Nepal`

Query	Precision	Recall	F1	# of relevant examples	# of irrelevant examples
Q1	0.67	0.82	0.73	81	315
Q2	0.82	0.91	0.86	47	253
Q3	0.94	0.91	0.92	27	213
Q4	0.91	0.80	0.85	13	227
Q5	0.85	0.92	0.88	36	144

Table 1. Classification results in terms of precision, recall and f-measure. Also, number of training examples in our relevant and irrelevant classes

T3: `Most Urgent Need in #Nepal: Search and Rescue capacity; Medical teams, more supplies and tenting for hospitals and body bags`

T4: `Urgent need of analgesic,antibiotics, betadiene, swabs in kathmandu!! Call for help DIGIT #earthquake #Nepal`

T5: `Earthquake survivors in Nepal urgently need help. Make an emergency donation to WFP`

To test the performance of the system, we train machine learning classifiers. Specifically, using the returned results against our queries, we manually labeled which tweets are relevant and which are not. In this case, our classification task consists of two classes. We use Random Forest as our learning scheme. For evaluation, we use 10-fold cross validation technique and we report precision, recall, and f-measure scores to show the classification performance.

Table 1 shows the results of the classification task. We can observe that overall the system performs good. Other than the results of Q1, all performance indicators show results >0.80. We also observe a low precision in the case of Q1, whereas recall for Q1 is in the acceptable range.

User Studies

In order to perform further validation of the system's performance, we conducted user studies using 8 participants. All of our participants are either Master's students, PhD students or professionals. All of our participants use Twitter in their daily routine to get latest updates and to post tweets (on average 2 posts per day). Table 2 shows more details of our participants.

To start, we verbally described the motivation behind the system, how it works along with a short demo, and details of our Nepal earthquake dataset. We present the system to each participant and ask them to run two to three queries of their choice. Figure 2 shows the screenshot of the system interface. Each participant was instructed to mark the tweets that they think are relevant to their queries. The participants actively used the system and tried different queries. At the end, we asked them the following questions.

1. Overall, do you think the system fulfilled your information needs?
2. Overall, do you think the tweets returned by the system were mostly relevant to your query?
3. Did you observe an improvement in the returned results while using the system?
4. Do you think the number of tweets shown on a page is easy to go through?
5. Do you think system was difficult to use?
6. Will you consider this system to search information during a crisis event?

For the above six questions, we used the following scale for a participant's answer. (i) Strongly Agree, (ii) Agree, (iii) Neutral, (iv) Disagree, (v) Strongly Disagree

Finally, we ask each participant regarding how would he/she rate overall experience using the system. We used options: (i) Highly satisfactory, (ii) Satisfactory, (iii) Neutral, (iv) Unsatisfactory (v) Highly Unsatisfactory)

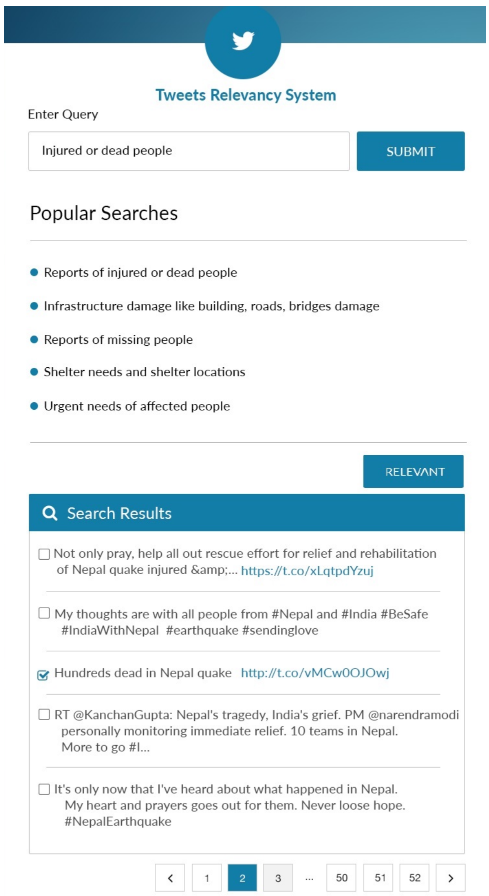

Figure 2. System used to show query results and to get users feedback

Table 2. Users demographic information

Users	Age	Gender	Education	Profession
U_1	30	Male	MSCS	Software Engineer
U_2	24	Male	BSSE	Entrepreneur
U_3	24	Female	MSIT	Software Engineer
U_4	26	Female	MSIT	Web Developer
U_5	35	Male	BSIT	SEO Expert
U_6	22	Male	BSCS	Android Developer
U_7	28	Female	PhD	Research Associate
U_8	30	Female	PhD	Student

Summary of Participants Feedback

Regarding the question 1, five out of eight participants agreed that
the system indeed helped them get the information that they aimed for. The remaining three chose the neutral option. We also observe the same trend in the case of 2nd question (5 out of 8 agreed). However, whether the system returned better results during different iterations, 6 participants agreed that the system improved by time (the other 2 chose neutral option). Most of the participants did not seem to have any issues with the number of tweets shown on a page (question 4) and none of the participants showed concerns regarding system usage difficulties. The participants also showed interest to use the system in future. In regards to the last question, we observe a ratio of 1:5:2 for highly satisfactory, satisfactory, and neutral respectively.

Discussion

Retrieval of relevant documents from a live data stream is generally a challenging task. However, due to limited contextual information, processing and extracting relevant information from Twitter data stream is a non-trivial task. In this work, we have employed a state-of-the-art technique (word2vec) useful to increase contextual information given a reference word/term. Once trained on a large corpus, word2vec embeddings can be useful to retrieve most contextual relevant terms to a given input word. However, one of the limitations of this technique, which we also inherit, is the lack of large domain-specific corpus for the training of a good word2vec model. To overcome this issue, we aim to collect more disaster-related datasets form Twitter to see if it improves our current results.

Moreover, another challenge in the current approach is to achieve optimal query vectors in a timely manner. Since this process involves human input (i.e., marking of relevant results), there is an inherit complexity to determine the optimal number of results to be shown to the users. The aim here is to reach an optimal query vector in fewer iterations (i.e., using fewer human annotations). Furthermore, training supervised classifiers always demand a good amount of training data. In our current experiments, it is evident that the number of training examples are very limited. However, in future we aim to overcome this issue by employing unsupervised techniques to get highly similar messages to the ones annotated by the users.

RELATED WORK

Given the widespread use of social media platforms, especially Twitter, during crises opens new opportunities for people in the disaster zone and humanitarian organizations to fulfill their rapid information needs in many forms, such as textual summaries, ranked output, classified images (Rudra et al. 2016; Ofli et al. 2016). Twitter is not only useful to consume important information, but also to quickly and effectively disseminate relevant information (M. Mendoza and Castillo 2010). On average different types of users (Uddin et al. 2014) post 500 million tweets per day[3]. Extracting useful information from such huge data, especially in real-time, is a challenging task. Much of this online information contains irrelevant stuff. For this purpose, many techniques have been proposed to convert such big data into useful information (MacEachren et al. 2011; Cameron et al. 2012; Terpstra et al. 2012). However, many state-of-the-art approaches, for example, supervised classification techniques require event-specific training data (Imran, Elbassuoni, et al. 2013). Despite, recent studies have explored ways to utilize

[3] http://www.internetlivestats.com/twitter-statistics/

labeled data from past events (Imran, Mitra, and Srivastava 2016), however, the need of event-specific labeled data to train better classifier has not been fulfilled yet.

Recently, there have been advances in core technologies useful for natural language processing. For instances, word2vec is one of them and is being used for a number of application areas. Word2vec is a form of word vector representations. Vector space model (VSM) represents embedded words in a vector space where semantically similar words are placed near to each other. This has received a great deal of attention in the natural language processing and machine learning communities for their ability to model term similarity and other relationships (Diaz et al. 2016).

Refining a query either uses a fully automatic approach or it can be optimized by adding a human in the loop. Adding relevant words to the context and subtracting irrelevant ones will eventually help in getting the fully optimized query. Optimal query helps maximizing the similarity to relevant documents while on the other hand it will minimize the similarity to non-relevant documents. The relevance feedback algorithm is one of the most popular and widely applied learning methods from information retrieval (Joachims 1996)

There are many systems that use the above mentioned methods in order to find out the relevant information but none of them is actually applicable for information extraction in real-time situations without labeled data. There is no real time system which will take users relevance feedback during a crisis situation and learn a supervised model. To fill these gaps, we proposed a novel approach that uses word2vec, query expansion, query optimization techniques to automatically train supervised machine learning classifiers to fulfill users information needs.

CONCLUSION

Affected people and humanitarian organizations have quick information needs during time of disasters and emergency situations. Existing studies indicate the social media content posted during a crisis to fulfill peoples information needs. However, obtaining relevant information from social media platform such as Twitter is not a trivial task. Despite advances in natural language processing and supervised classification techniques, fast access to relevant information is still a challenging task. In this work, we propose a novel solution based on query expansion and relevance feedback mechanism to simultaneously retrieve relevant information and training of a supervised classifier. Initial results show the potential of the proposed approach. However, further investigation using datasets from other crises has to be done, which we consider as future work.

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Towards Practical Usage of a Domain Adaptation Algorithm in the Early Hours of a Disaster

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ABSTRACT

Many machine learning techniques have been proposed to reduce the information overload in social media data during an emergency situation. Among such techniques, domain adaptation approaches present greater potential as compared to supervised algorithms because they don't require labeled data from the current disaster for training. However, the use of domain adaptation approaches in practice is sporadic at best. One reason is that domain adaptation algorithms have parameters that need to be tuned using labeled data from the target disaster, which is presumably not available. To address this limitation, we perform a study on one domain adaptation approach with the goal of understanding how much source data is needed to obtain good performance in a practical situation, and what parameter values of the approach give overall good performance. The results of our study provide useful insights into the practical application of domain adaptation algorithms in real crisis situations.

Keywords

Twitter, Domain adaptation, Disaster, Classification

INTRODUCTION

With the prevalent usage of social media, we often see newspapers or TV stations citing texts and images posted on Twitter by eye-witnesses of emergency events. Such first-hand information during emergencies has the potential to also help emergency teams to improve situation awareness and response (Castillo 2016; Hughes et al. 2014; Reuter et al. 2015; Starbird et al. 2010; Landwehr and Carley 2014; Palen, Vieweg, et al. 2011). In practice, however, large-scale disaster response organizations haven't extensively adopted the use of such social media data (Tapia and Moore 2014). A survey of emergency managers in U.S.A. at county level (Plotnick et al. 2015) and surveys of emergency staff in some European countries (Reuter et al. 2015) show that although the responding officers see social media as being useful, many challenges still impede the extensive adoption of social media data in operations. These challenges include both management challenges such as lack of guidance, lack of staff, and technical challenges such as information overload, and reliability or trustworthiness of the information source.

Many recent research works have used machine learning approaches on social media data gathered during emergency events. Such works have suggested that automated approaches based on machine learning can enable management and response organizations sift through large amounts of information, and prioritize the information to be carefully analyzed based on relevance, reliability, trustworthiness, etc. (Imran, Elbassuoni, et al. 2013; Imran, Mitra, et al. 2016; C. Caragea, Squicciarini, et al. 2014; C. Caragea, Silvescu, et al. 2016; Li, Guevara, et al. 2015; Imran, Castillo, et al. 2015). However, machine learning algorithms cannot be easily deployed and used in emergency situations due to different challenges, depending on the algorithms.

One big challenge for supervised learning algorithms is that such algorithms require labeled data from a current disaster of interest, i.e. tweets labeled as relevant to the disaster or not-relevant, tweets labeled as relevant and informative versus tweets labeled as relevant but not-informative, etc. Unfortunately, it is not realistic to assume that labeled data for a current disaster is readily available, as trustworthy labels require significant time and effort. However, it is reasonable to assume that labeled data is available for a prior disaster, called "source", and several works have focused on learning supervised classifiers for the "target" disaster based on a "source" disaster (Imran, Elbassuoni, et al. 2013; Imran, Mitra, et al. 2016). One drawback of this approach is that the classifiers learned from a prior source disaster may not generalize well to the target disaster (Imran, Elbassuoni, et al. 2013; Verma et al. 2011), as the target disaster may have unique characteristics in terms of its nature, location, etc. and may also cause different social media response (Palen and Anderson 2016).

Domain adaptation algorithms (Li, Guevara, et al. 2015) that make use of target unlabeled data in addition to source labeled data represent a good alternative to supervised classifiers learned from labeled source data only, given that unlabeled data from the target disaster accumulates quickly. The algorithm proposed in (Li, Guevara, et al. 2015) is an iterative algorithm based on Expectation Maximization (EM). A variant of this algorithm, based on the idea of self-training, has been introduced in our prior work (Li, D. Caragea, et al. 2017). Our prior experimental results have shown that the self-training variant gives results comparable, and sometimes better, than the EM variant. More importantly, both variants result in classifiers that are significantly better than the supervised classifiers learned from labeled source data only. Furthermore, the self-training variant is more appropriate for scenarios where more unlabeled target data may become available during the algorithms' later iterations. Such scenarios better reflect the reality, making the self-training approach more desirable when attempting to use domain adaptation algorithms in practice during an emergent disaster.

However, there are other challenges that prevent the self-training domain adaptation approach from being deployed in a real situation. First, to be able to successfully deploy this approach, it is important to understand how much source labeled data the algorithm needs, as too little labeled data may result in inaccurate classifiers, while too much labeled data may not be worth the effort of labeling it. Thus, our first objective is to study the variation of the performance of this domain adaptation algorithm with the amount of labeled source data. Second, the algorithm has two parameters that need to be tuned, a parameter that controls the weights assigned to the source and target data during training, and a parameter that controls the number of target instanced added to the classifier at each iteration. Parameter tuning is not a challenge specific to domain adaptation. In fact, many supervised learning algorithms require tuning for best performance, a process that can be time consuming. But in addition to being time consuming, in a domain adaptation scenario, parameter tuning requires labeled data from the target disaster. Under the assumption that labeled data is not available for the target disaster, parameter tuning becomes impractical.

To address these issues, we use a relatively large number of (source, target) pairs and study the performance of the self-training domain adaptation algorithm under different amounts of labeled source data, with the goal of identifying the size of source data that the algorithm needs. We then study how the performance changes when varying the parameters of the algorithm. The objective is to identify parameter values that work well for a large number of (source, target) pairs, and use those values as default values when deploying a domain adaptation in practice, thus avoiding the need for parameter tuning in a real scenario.

In addition, we study the performance of the algorithm with the number of iterations. As mentioned earlier, the algorithm terminates when there is no change in the labels of the current instances in the target data, in between two consecutive iterations. We can think of this condition as a pseudo-convergence condition, in the sense that if the labels don't change in between two consecutive iterations, the classifiers will presumably not change much if the most confidently labeled instances at the last iteration are still added to the training data. However, in practice, the addition of the most confidently labeled instances can result in a classifier with performance different from the performance of the classifier at pseudo-convergence. The objective is to understand if the algorithm should terminate when the pseudo-convergence condition is met, or if it should run for a certain number of iterations (dependent on the number of target unlabeled instances to be added to the training data).

We summarize our main contributions as follows:

- We evaluate the performance of the domain adaptation algorithm with self-training on a relatively large set of (source, target) pairs, when using different amounts of labeled source data. The goal is to identify a good trade-off between the amount of labeled source data necessary for good performance and the effort to label that data.
- We evaluate the performance of this algorithm when varying its parameters. The goal is to identify parameter values that give good results, in general, and use those values as default values in a realistic scenario, where tuning is impractical.

- We also evaluate the performance of the algorithm when varying the number of iterations. The goal is to identify the number of iterations that leads to the best performance, in general, and use that number as a default value in a realistic scenario.

METHOD

We focus on the task of classifying tweets posted during a disaster as related to the disaster, or *on-topic*, and not related to the disaster, or *off-topic*. This is one of the most important classification tasks as many other tasks during a disaster are performed on tweets relevant to a disaster. Furthermore, this is a task where supervised classifiers learned from source only do not generalize well (Li, Guevara, et al. 2015). While any algorithm, including Naïve Bayes, Random Forest (RF), Support Vector Machines (SVM), Logistic Regression (RF), etc. can be used with domain adaptation, we choose to use the Naïve Bayes algorithm as it doesn't have any parameters that need to be tuned. Furthermore, our prior work (Li, D. Caragea, et al. 2017) has shown that for our classification task, Naïve Bayes gives better results than the RF, SVM, LR algorithms with default parameters (without tuning).

We implemented a version of self-training domain adaptation based on (Li, Guevara, et al. 2015; Herndon and D. Caragea 2015). The self-training domain adaptation builds a weighted Naïve Bayes Bernoulli (Manning et al. 2008) classifier, which linearly combines source and target data in an iterative fashion, to simultaneously estimate the prior $P(c_i)$ and the likelihood $P(w_j|c_i)$, as follows:

$$P(c_i) = (1-\gamma)P_{SL}(c_i) + \gamma P_{TU}(c_i) \tag{1}$$

$$P(w_j|c_i) = (1-\gamma)P_{SL}(w_j|c_i) + \gamma P_{TU}(w_j|c_i) \tag{2}$$

In the equations above, c_i represents a class label, w_j is a feature in the feature set or vocabulary V, the probability subscript (SL or TU) denotes the type of data used to estimate that probability, i.e. SL denotes source labeled data, TU denotes target unlabeled data, and δ is a parameter that controls how fast we shift the weight from source to target data. This parameter is defined as $\gamma = \min(t * \delta, 1)$, where $t = \{0, 1, 2, \cdots\}$ is the iteration number. Initially, $t = 0$, $\gamma = 0$, which means that only source labeled data is used. Then, according to the Bayes Theorem, we estimate the posterior class label c_i for a new instance d as:

$$P(c_i|d) \propto P(c_i) \prod_{j \in |V|} P(w_j|c_i) \tag{3}$$

At each iteration, the current classifier (originally trained only from source labeled data) is used to classify the remaining target unlabeled data (originally all the target unlabeled data). The most confidently classified unlabeled instances (e.g., top k instances in each class) are moved to the training set, with hard (e.g., 0/1) labels, to be used in subsequent iterations. By default, the algorithm runs until convergence, where "convergence" means that the labels of the remaining target unlabeled instances don't change in between two consecutive iterations (Yarowsky 1995). The domain adaptation approach with self-training is summarized in Algorithm 1 below.

So the algorithm has two parameters that need to be tuned, a parameter δ which defines how fast we shift the weight from source to target data, and another parameter k which defines how many instances of each class to add at each iteration while training.

DATASET

CrisisLexT6 dataset is a collection of English tweets from six disasters, published by (Olteanu et al. 2014). This dataset is collected through Twitter API based on keywords and geo-locations of affected areas. The six disasters all occurred between October 2012 and July 2013 in USA, Canada and Australia. There are approximately 10,000 tweets for each disaster, all manually labeled as on-topic or off-topic through the crowdsourcing platform Crowdflower. We used the same pre-processing as in (Li, Guevara, et al. 2015) to clean the tweets, including removing non-printable ASCII characters; replacing URLs, email addresses, and usernames with an URL/EMAIL/USERNAME placeholder, removing RT (i.e., re-tweet) and duplicate tweets etc. Furthermore, we represented both source disaster tweets and target disaster tweets as feature vectors (using the bag-of-words 0/1 representation), where the features are words that appear in the target disaster with frequency as least 10. Thus, the vocabulary size is different for different target disasters, but generally each vocabulary consists of around 1000 features for the source/disaster pairs that we chose to experiment with. We do not perform additional feature selection as we assume that target labeled data is not available. The statistics for the final dataset are shown in Table 1, sorted based on the time when each disaster happened.

Algorithm 1: Naïve Bayes Domain Adaptation algorithm with self-training

1. Given: Target unlabeled data TU, source labeled data SL and target test data TT
2. Initialize $TU_{hard} = \phi$ and $TU_{left} = TU$, where TU_{hard} is the set of instances with hard labels assigned by self-training, and TU_{left} is the set of unlabeled instances left in TU
3. Use SL and TU_{hard} to simultaneously compute the prior and likelihood with Equations 1 and 2, respectively. At the first iteration, only SL is used
4. Compute the posterior class probability of target instances still unlabeled, TU_{left}, with Equation 3
5. Select the k most confidently labeled instances from each class c_i based on probability ranking, move them to TU_{hard} (to use for training in the next iteration) and remove them from TU_{left}
6. **while** *(labels assigned to instances in TU_{left} change) or (maximum number of iteration not reached)* **do**

   M-step: Simultaneously compute the prior and likelihood using Equations 1 and 2, respectively, using a combination of SL and TU_{hard} weighted based on $\gamma = \min(t * \delta, 1)$, where t is the iteration number

   E-step: Compute the posterior class probability of target instances still unlabeled, TU_{left}, with Equation 3 and select the k most confidently labeled instances as in Step 4

   end
7. Use the final classifier to predict the labels of the target test instances TT

Table 1. Number of instances for each disaster in the dataset, before and after cleaning

	Before Cleaning			After Cleaning		
Crisis	On-topic	Off-topic	Total	On-topic	Off-topic	Total
2012_Sandy_Hurricane	6138	3870	10008	5261	3752	9013
2013_Queensland_Floods	5414	4619	10033	3236	4550	7786
2013_Boston_Bombings	5648	4364	10012	4441	4309	8750
2013_West_Texas_Explosion	5246	4760	10006	4123	4733	8856
2013_Oklahoma_Tornado	4827	5165	9992	3209	5049	8258
2013_Alberta_Floods	5189	4842	10031	3497	4714	8211

EXPERIMENTAL SETUP

Our experimental setup is designed to help us understand the use of the domain adaptation algorithm from a practical point of view. First, we want to understand how many source instances are needed to learn an accurate classifier for a target disaster in a domain adaptation setting. Second, we aim to understand how the performance of the domain adaptation classifier varies with parameters δ and k values, and to select good overall values to use in practice. Third, we aim to study how the performance varies with different numbers of iterations, and to identify an appropriate number of iterations for good performance. More specifically, we ask the following questions:

- *How many source labeled instances are needed to build an accurate classifier for the target?*
- *What values should we use in practice for the parameters δ and k of the domain adaptation algorithms?*
- *How many iterations are needed to build an accurate classifier for the target?*

To answer these questions, we follow the timeline of the six disasters in the dataset and select a variety of disaster pairs to perform experiments. Except for Hurricane Sandy, which does not have a prior disaster in this dataset, all the other disasters are used as target disasters in one or more pairs. We end up with 11 pairs, which cover natural disaster pairs, man-made disaster pairs, and also natural and man-made disaster pairs. When reporting the results, we arrange pairs having the same target disaster but different source disasters together, and represent each pair with its initials of the source and target disasters, as shown in Table 2.

Table 2. Source-Target pairs of disasters used in the experiments

Pair	Source Disaster	Target Disaster
SH -> QF	2012_Sandy_Hurricane	2013_Queensland_Floods
SH -> BB	2012_Sandy_Hurricane	2013_Boston_Bombings
QF -> BB	2013_Queensland_Floods	2013_Boston_Bombings
SH -> WTE	2012_Sandy_Hurricane	2013_West_Texas_Explosion
BB -> WTE	2013_Boston_Bombings	2013_West_Texas_Explosion
SH -> OT	2012_Sandy_Hurricane	2013_Oklahoma_Tornado
QF -> OT	2013_Queensland_Floods	2013_Oklahoma_Tornado
BB -> OT	2013_Boston_Bombings	2013_Oklahoma_Tornado
SH -> AF	2012_Sandy_Hurricane	2013_Alberta_Floods
QF -> AF	2013_Queensland_Floods	2013_Alberta_Floods
BB -> AF	2013_Boston_Bombings	2013_Alberta_Floods

Training and test data: For each pair, we use 5-fold cross-validation to select target unlabeled data and target test data. Specially, we split the target data into 5 folds; at each rotation, one fold is used as target test data (TT), and three folds are used as target unlabeled data (TU) to be used in domain adaptation together with source labeled data (SL). The last fold is reserved for potential usage as target labeled data in future work. To choose different amounts of source labeled data for each pair, we randomly select 250, 500, 1000, 2000 instances from each class (on-topic/off-topic), and then finally include all instances from each c lass. Thus, we end up with SL-500, SL-1000, SL-2000, SL-4000 and SL-ALL number of source instances, respectively. The number of all instances for each disaster is around 8000 after cleaning, except for Hurricane Sandy whose number is around 9000.

Parameter tuning: To report best performance for a pair, we tune parameters δ and k during a validation step. We randomly select one of the three target unlabeled (TU) folds as validation data (TTV), and use the other two folds of TU as target unlabeled data for validation (TUV). We use SL+TUV for training and TTV and select the best values for the parameters based on TTV. After tuning, the whole TU is used to learn the final classifier for the target, and performance is estimated using the target test set TT. The values used for δ are: {0.001, 0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9}, and the values used for k are {1,5,10}.

Experiments: We perform several experiments on each pair of disasters. The first experiment is domain adaptation with self-training running until convergence, with parameter values tuned based on the validation data. We refer to this experiment as NB-STT-Conv. The second experiment, NB-STF-Conv, is similar to the first one, except that the algorithm runs with fixed values for parameters δ and k . We compare the results of these experiments to understand how much is lost, if anything, by fixing parameters.

To see whether the performance can still improve after convergence, we also vary the number of iterations for fixed δ and k parameters, beyond convergence. The following value are considered for the number of iterations: {10, 50,100,150,200,250,300}, and the best number of iterations, among those considered, is identified. We refer to the experiment where the algorithm runs with fixed parameters δ and k, and fixed number of iterations as NB-STF-Iter. The results of all experiments are reported in terms of the area under the ROC curve (auROC), but other measures (e.g., accuracy) show similar trends.

EXPERIMENTAL RESULTS AND DISCUSSION

To answer our research questions, we first run the algorithm using source datasets of different sizes and tune parameters. We then analyze how the performance varies with different values for parameters δ and k, when running until convergence. We identify the general best values for those parameters. Then, using the selected δ and k values, we study the performance of the algorithm when increasing the number of iterations, and identify a good number of iterations to use instead of convergence. We answer the research questions in the following discussion.

How many source labeled instances are needed to build an accurate classifier for the target?

Table 3 shows the variation of the performance with the size of the source dataset. We performed column-wise paired t-tests $p \leq 0.05$) to compare the results in a row and identify values that are significantly better than their counterparts. The best values for each row/pair are shown in bold. As can be seen, the performance generally increases with the amount of labeled source data. However, between using 4000 instances and using all instances

Table 3. Variation of the performance of the domain adaptation algorithm with the size of the source dataset. The supervised Naïve Bayes classifier learned from all source data is used as a baseline. Performance is reported as weighted auROC values obtained using parameter tuning (averaged over 5 folds). The algorithm terminates upon convergence (NB-STT-Conv). The best value in each row is shown in bold (based on a t-test with $p \leq 0.05$).

Pair	Baseline	SL-500	SL-1000	SL-2000	SL-4000	**SL-All**
SH -> QF	0.911	0.945	0.955	0.964	0.971	**0.974**
SH -> BB	0.753	0.877	0.914	0.926	0.935	**0.941**
QF -> BB	0.820	0.840	0.863	0.866	**0.890**	**0.890**
SH -> WT	0.853	0.973	0.972	0.976	**0.986**	**0.987**
BB -> WT	0.983	0.969	0.972	0.972	**0.980**	**0.984**
SH -> OT	0.865	0.921	0.932	0.944	**0.953**	**0.951**
QF -> OT	0.880	**0.916**	**0.921**	**0.919**	**0.926**	**0.924**
BB -> OT	0.905	0.919	0.924	0.927	**0.942**	**0.944**
SH -> AF	0.830	0.925	0.942	0.956	**0.970**	**0.972**
QF -> AF	0.860	0.880	0.890	0.892	0.918	**0.922**
BB -> AF	0.806	0.898	0.912	0.935	**0.950**	**0.950**

(approximately 8000), the performance does not increase much. In fact, for 7 out of 11 pairs, the results obtained with 4000 instances are as good as the results obtained with all source instances, suggesting that the effort that goes into data labeling is not worth beyond 4000 instances. Furthermore, we can also see that as few as 500 source instances can produce classifiers with performance close to 90%, and most of the time better than the performance of the supervised classifiers learned from all the source data. Therefore, if labeling 4000 instances is not possible, the domain adaptation algorithm can still help as compared to the supervised learning algorithm.

What values should we use in practice for the parameters δ and k of the domain adaptation algorithms?

Figures 1 and 2 show the variation of performance with parameters δ and k, respectively. In each figure, the variation of performance when 500 source instances are used is shown on the left, whereas variation when 4000 source instances are used is shown on the right. We focus on 500 and 4000 instances, respectively, to understand if the best values for parameters are different for smaller versus larger source datasets. In all cases, the algorithm is run to convergence.

Subplots (a), (b), (c) in Figure 1, show the variation of the performance with δ when 500 source instances are used, and k is fixed to 1, 5, 10, respectively. Similarly, subplots (d), (e), (f) in Figure 1, show the variation of the performance with δ when 4000 source instances are used, and k is fixed to 1, 5, 10, respectively. We can see that when we have 4000 source instances, the best results are generally obtained for a very small value of δ, specifically 0.001, regardless of the value used for k. This result suggests that a source with 4000 instances produces a reasonably good classifier in the first place, and therefore the shift from the source to the target should be done slowly to allow for the accumulation of accurately labeled target instances in the training set. Another interesting observation is that for values of δ greater than 0.1, the performance does not change much. This is because when δ is large, the algorithm shifts all the weight to the target data in a small number of iterations. For example, when $\delta = 0.2$, the weight assigned to the target will be 1.0 at the sixth iteration ($\min(5 * 0.2, 1) = 1$), and thus the classifier solely depends on the self-training of the target unlabeled instances added in the first 5 iterations, which will lead the algorithm to converge very fast.

When 500 source instances are used, the best results are also obtained with small values of δ, but the best value is not consistent as 0.001. In some cases, the best δ value is 0.01 or 0.1, which shows that the shift from source to target happens faster when the original classifier learned from source is not very good. In effect, a higher weight will be assigned to the target data, which is still small in size and possibly not very accurate. Given that, from a practical point of view, it is desirable to have a larger amount of source data (approximately 4000), as that makes it easier to find good overall values for the parameter δ.

Subplots (a), (b), (c) in Figure 2 show the variation of the performance with k when 500 source instances are used, and δ is fixed to 0.001, 0.01, 0.1, respectively. Similarly, subplots (d), (e), (f) in Figure 2 show the variation of the performance with δ when 4000 source instances are used, and δ is fixed to 0.001, 0.01, 0.1, respectively. By analyzing these plots, we can see that when δ is very small, for example 0.001, the performance is more steady, generally increasing very slowly with k, with some exceptions (e.g., SH -> AF in Figure 2 (a)). In particular, for

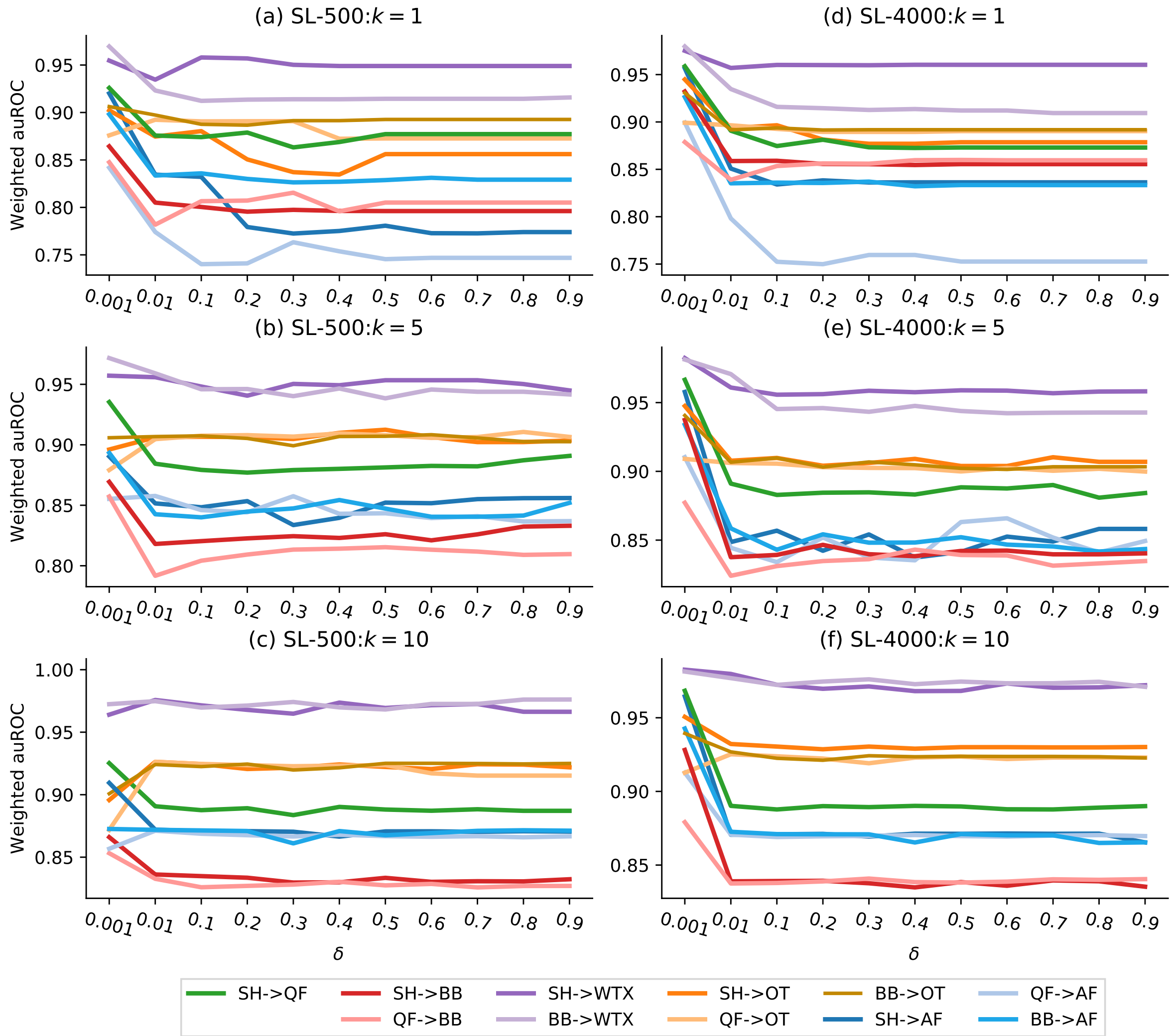

Figure 1. Variation of the performance (auROC) with δ for two sizes of the source dataset: SL-500 (left) and SL-4000 (right). The parameter k is fixed to 1, 5, and 10, respectively. The algorithm terminates upon convergence.

4000 source instances and $\delta = 0.001$, the best performance is observed for either $k = 5$ or $k = 10$. The performance decrement from $k = 5$ to $k = 10$ that is observed for some pairs can be explained by the addition of mislabeled target instances to the training data, which can easily happen when too many target instances are added at once. When δ is 0.01 or 0.1, the increase/decrease pattern is less consistent overall, although for many pairs larger k is better.

Figures 1 and 2 together suggest that the best performance overall is obtained when the source data consists of approximately 4000 instances, parameter δ is set to 0.001 and parameter k is set to 5 or 10. Furthermore, even when only 500 source instance are available, the same parameters can be used.

To understand if performance is sacrificed when fixing parameters as opposed to tuning them, we compare the two settings when the algorithm runs to convergence. The results are shown in Table 4. As can be seen, the results obtained using fixed parameter values are as good as the results obtained using tuned values for most pairs, with only two exceptions for ST-4000 (QF -> BB, QF->OT) and two exceptions for ST-500 (QF->OT and SH -> WTE), where the performance with fixed values is just slightly worse than the performance with tuned values.

How many iterations are needed to build an accurate classifier for the target?

Using the findings about best overall parameters, our next objective is to compare the performance when the algorithm terminates upon convergence versus performance when the algorithm terminates after a fixed number of iterations, identified as a good overall number of iterations during validation. Specifically, we run experiments with fixed parameters δ and k, and vary the number of iterations. The results on the target validation data are shown in Figure 3, for 500 source instances (left) and 4000 source instances (right). The dot on each curve represents

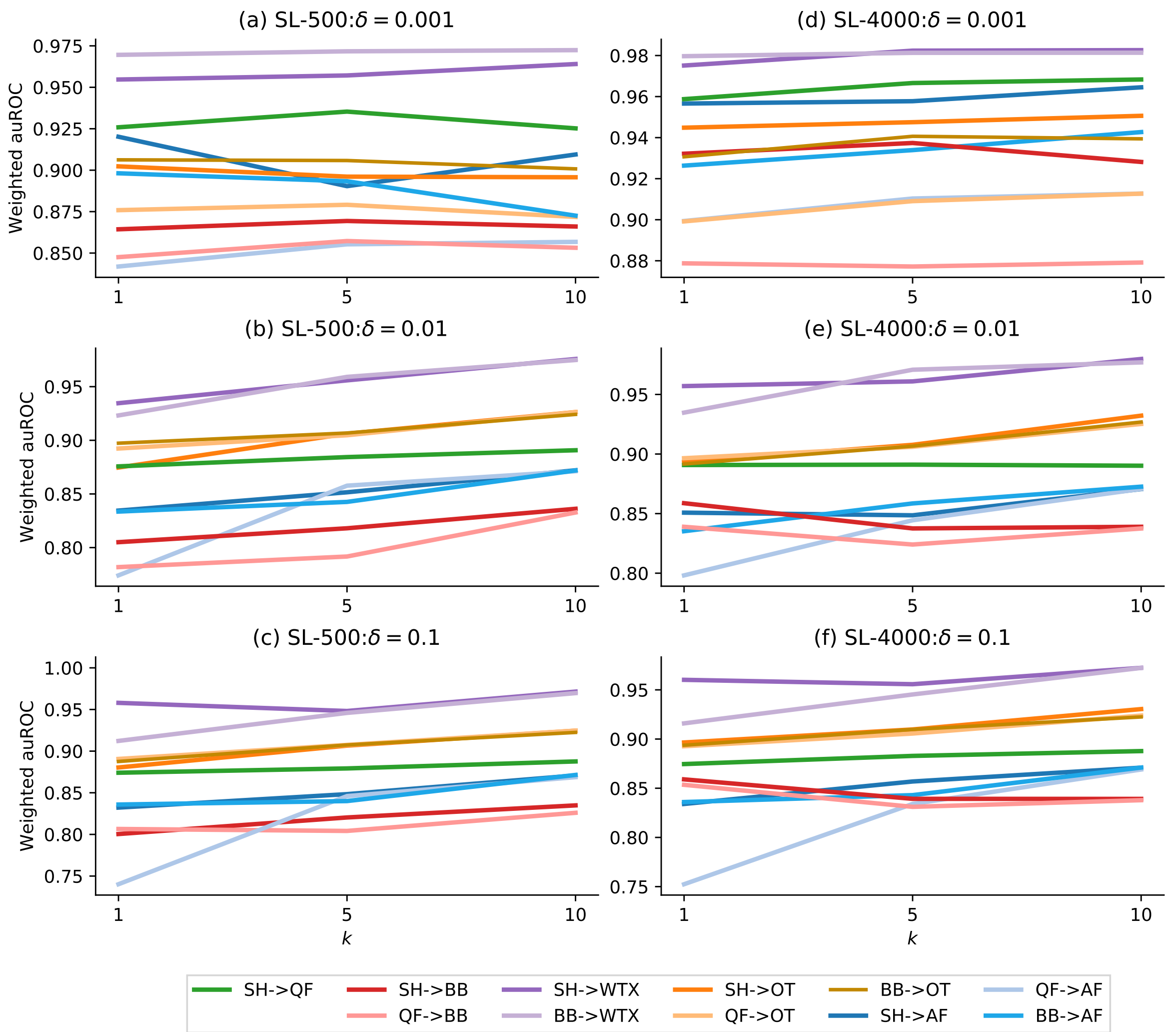

Figure 2. Variation of performance (auROC) with k for two sizes of the labeled source data: SL-500 (left) and SL-4000 (right). Parameter δ is fixed to 0.001, 0.01 and 0.1, r espectively. The algorithm terminates upon convergence.

the number of iterations at "convergence" for the corresponding pair on a curve. As can be seen, the performance generally increases with the number of iterations, beyond the number of iterations at which "convergence" is reached. However, after a certain number of iterations (equivalently, after a certain number of target instances have been added to the training set), the performance does not change much. As expected, the number of iterations at which performance stabilizes is larger for $k = 5$ as compared to $k = 10$, as less target instances are added to the training data, at each iteration, for $k = 5$. In particular, the performance becomes stable around 250/300 iterations for $k = 5$ and around 150 iterations for $k = 10$. For $k = 5$, 300 iterations correspond to 5x2x300=3000 target instances being added to the training data, while for $k = 10$, 150 iterations correspond to 2x10x150=3000 target instances as well. This result suggests that the number of target instances to be included in the training dataset needs to be greater than 3000 for best performance. However, it is important to note that the algorithm can start with the unlabeled target data available at the onset of a disaster. As more unlabeled target data becomes available at a later time, that data can be used in subsequent iterations of the domain adaptation algorithm, in an online fashion.

Table 5 shows the results of the algorithm when run with fixed parameters $\delta = 0.001$ and $k = 5$ and two termination conditions, respectively: convergence (NB-STF-Conv) and fixed number of iterations, specifically 300 iterations (NB-STF-Iter). As can be seen, the results are almost aways better when using a fixed number of iterations, therefore running the algorithm beyond pseudo-convergence is generally advantageous.

In summary, our empirical results suggest that fixing the algorithm's parameters δ and k, and fixing the number of iterations n can be done without scarifying performance. In turn, this finding makes it possible to use our domain

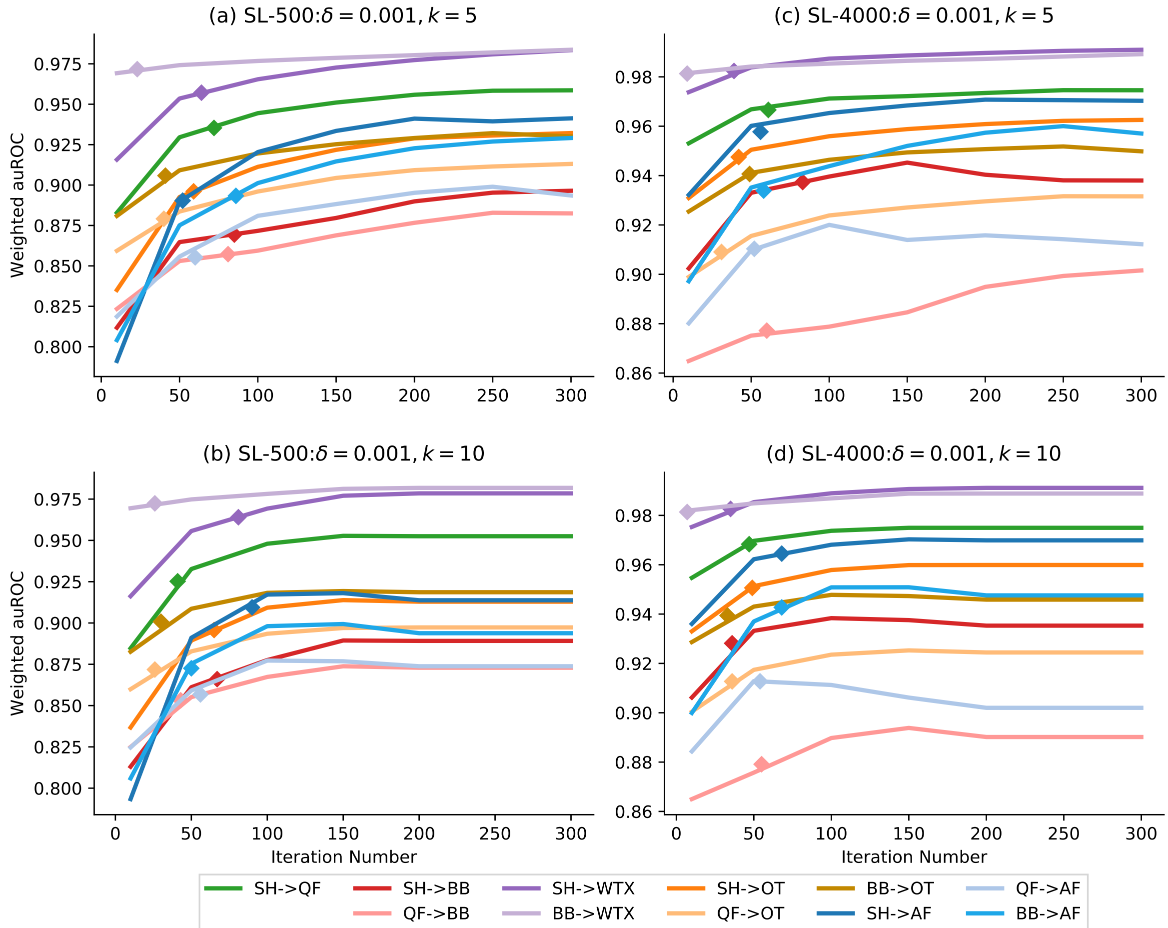

Figure 3. Variation of performance (auROC) with the number of iterations for two sizes of the labeled source data: SL-500 (left) and SL-4000 (right). The dots on each curve represent the performance at "convergence."

adaptation approach in a practical situation, where target labeled data for tuning parameters is not available, but batches of unlabeled target data accumulate quickly in an online fashion.

RELATED WORK

In the context of automatically classifying disaster data, several research papers have studied supervised learning algorithms in regard to transferring information from a prior source disaster to a current target disaster (Imran, Elbassuoni, et al. 2013; Imran, Mitra, et al. 2016; Verma et al. 2011; Rudra et al. 2015). Verma et al. (2011) used natural language processing techniques together with machine learning algorithms, both Naïve Bayes and Maximum Entropy, to identify situational awareness tweets belonging to four crisis events. They studied how well the Maximum Entropy classifiers performed across the four events and found that the classifiers didn't generalized well across different types of disasters. In a similar study, Imran, Mitra, et al. (2016) used Random Forest classifiers and achieved good results for disasters of the same type, but not for disasters of different types. Imran, Elbassuoni, et al. (2013) performed experiments on two disasters, Joplin Tornado (as source) and Hurricane Sandy (as target), with the goal of identifying information nuggets. After classifying different types of informative (casualties, donations, etc.) tweets with Naïve Bayes classifiers, they used a machine-learning sequence labeling algorithm, conditional random fields (CRF), to extract useful information, such as the number of casualties or the name of the infrastructure. Their experiments showed that using source data only results in a significant drop in the detection rate, while not affecting significantly the recall.

Most of these supervised algorithms, e.g., Maximum Entropy, Random Forest, are well developed and have been used extensively in text classification, but have hyper-parameters that need to be t uned. When applying these supervised algorithms to classify disaster social media data, default parameter values may not produce models as good as those obtained when tuning parameters. Furthermore, supervised classifier learned from a prior source disaster only may not perform well on an emergent target disaster as suggested by (Verma et al. 2011; Imran,

Table 4. Tuning results (NB-STT-Conv) versus results with fixed parameters $\delta = 0.001$ and $k = 5$ (NB-STF-Conv). In both cases, the algorithm terminates upon convergence. Best value in each column of a pair is shown in bold (row-wise t-test with $p \leq 0.05$).

Pair	Experiment	SL-500	SL-4000
SH -> QF	NB-STT-Conv	**0.945**	**0.971**
	NB-STF-Conv	**0.949**	**0.967**
SH -> BB	NB-STT-Conv	**0.877**	**0.935**
	NB-STF-Conv	**0.873**	**0.938**
QF -> BB	NB-STT-Conv	**0.840**	**0.890**
	NB-STF-Conv	**0.855**	0.878
SH -> WTE	NB-STT-Conv	**0.973**	**0.986**
	NB-STF-Conv	0.959	**0.985**
BB -> WTE	NB-STT-Conv	**0.969**	**0.980**
	NB-STF-Conv	**0.973**	**0.983**
SH-> OT	NB-STT-Conv	**0.921**	**0.953**
	NB-STF-Conv	**0.910**	**0.931**
QF -> OT	NB-STT-Conv	**0.916**	**0.926**
	NB-STF-Conv	0.893	0.914
BB -> OT	NB-STT-Conv	**0.919**	**0.942**
	NB-STF-Conv	**0.911**	**0.942**
SH -> AF	NB-STT-Conv	**0.925**	**0.970**
	NB-STF-Conv	**0.928**	**0.965**
QF -> AF	NB-STT-Conv	**0.880**	**0.918**
	NB-STF-Conv	**0.864**	**0.919**
BB -> AF	NB-STT-Conv	**0.898**	**0.950**
	NB-STF-Conv	**0.894**	**0.946**

Table 5. Results with fixed parameters when the algorithm runs to convergence (NB-STF-Conv) or for a fixed number of iterations (NB-STF-Iter), specifically 300 iterations. Best value in each column of a each pair is shown in bold (row-wise t-test with $p \leq 0.05$).

Pair	Experiment	SL-500	SL-4000
SH -> QF	NB-STF-Conv	0.949	**0.967**
	NB-STF-Iter	**0.957**	**0.972**
SH -> BB	NB-STF-Conv	0.873	**0.938**
	NB-STF-Iter	**0.893**	0.935
QF -> BB	NB-STF-Conv	0.855	0.878
	NB-STF-Iter	**0.880**	**0.898**
SH -> WTE	NB-STF-Conv	0.959	0.985
	NB-STF-Iter	**0.980**	**0.990**
BB -> WTE	NB-STF-Conv	0.973	0.983
	NB-STF-Iter	**0.981**	**0.987**
SH-> OT	NB-STF-Conv	0.910	0.950
	NB-STF-Iter	**0.938**	**0.962**
QF -> OT	NB-STF-Conv	0.893	0.914
	NB-STF-Iter	**0.919**	**0.933**
BB -> OT	NB-STF-Conv	0.911	0.942
	NB-STF-Iter	**0.934**	**0.952**
SH -> AF	NB-STF-Conv	0.928	**0.965**
	NB-STF-Iter	**0.940**	**0.968**
QF -> AF	NB-STF-Conv	0.864	**0.919**
	NB-STF-Iter	**0.902**	**0.916**
BB -> AF	NB-STF-Conv	0.894	0.946
	NB-STF-Iter	**0.932**	**0.959**

Elbassuoni, et al. 2013; Li, Guevara, et al. 2015 and our own work (Li, D. Caragea, et al. 2017)). At last, the works mentioned before use source data sets of varying sizes, and it is not clear how that affects the performance.

In terms of unsupervised domain adaptation, Li, Guevara, et al. (2015) proposed a domain adaptation algorithm based on EM. Their algorithm makes use of target disaster unlabeled data, together with source disaster labeled data, and produces classifiers that are better than the supervised classifiers learned from labeled source data only. Li, Guevara, et al. (2015) experimented with three classification tasks from two disasters, Hurricane Sandy (used as source) and Boston Bombing (used as target), with promising results on the task of identifying tweets relevant to a certain disaster. As opposed to the algorithm proposed by Li, Guevara, et al. (2015), our domain adaptation variant uses self-training, enables the learning process to start quickly (when only a small number of target unlabeled data is available) and allows for incremental updates of the target unlabeled data, as more target unlabeled data becomes available. This makes our variant more appropriate for a real scenario.

C. Caragea, Silvescu, et al. (2016) explored the use of Convolutional Neural Networks (CNN) to classify informative tweets from six flood e vents. Their idea to identify overall good parameters for the models is similar to the idea in our paper. To implement this idea, they used three flood disaster datasets with labeled instances, tuned parameters on one dataset and tested them on the other two test datasets to see how well the tuned parameters generalize. Nguyen et al. (2016) used convolutional neural networks (CNN) to classify crisis related tweets. They assumed that some target labeled data is available and used two simple supervised domain adaptation techniques to combine prior source disasters data with current disaster labeled data during training. One technique was weighting the prior source disasters data, while regularizing the modified m odel. The other technique was simply selecting a subset of the prior source disaster tweets, specifically those that were correctly labeled by a target-based classifier. Experimental results showed that CNNs with the simple instance selection domain adaptation technique gave better results. One drawback of these approaches is the requirement that some target labeled data is available.

At last, Zhang and Vucetic (2016) proposed another supervised domain adaptation approach that requires target labeled data, and used the dataset that we also used. Their proposed approach first clustered words from unlabeled tweets, and then trained a logistic regression classifier on labeled disaster tweets represented with the word clusters as features. They varied the number of current disaster labeled instances and found that the performance was generally better with more labeled data. This result is similar to our result that suggests that the more source labeled data, the better the performance. However, we found out that for our domain adaptation approach, more source labeled data can help up to a point when the performance stabilizes (in our experiments, the performance stabilized at 4000 source labeled instances). Zhang and Vucetic (2016) also varied the number of unlabeled instances from the current disaster and/or other source disasters, and even pre-trained a vocabulary based on word clustering. They found that more unlabeled data gives better results, in general, with some exceptions. In our experiments, the performance stabilized around 3000 target unlabeled instances.

CONCLUSION

The value of social media data, such as Twitter data, in emergency situations has been widely recognized by researchers. However, emergency organizations haven't extensively adopted such data in practice due to many challenges, including, information overload and reliability of data, among others. At the same time, many machine learning and data analysis techniques and systems have been proposed to address the information overload problem. Unfortunately, many machine learning algorithms require parameter tuning to build a good model, and this represents a big challenge when labeled data for tuning is not available (as it's the case in a current crisis situation). To address this challenge, we studied an unsupervised domain adaptation algorithm inspired by Li, Guevara, et al. (2015) on the the very first task aimed at reducing information overload on Twitter disaster data, specifically the task of classifying tweets as related to the disaster of interest or not related.

Our study provides recommendations for good overall parameter values to be used in practice for the domain adaptation algorithm with self-training. Furthermore, our study provides recommendations with respect to the number of labeled source instances to be used for good performance, and also with respect to the number of iterations needed for good performance.

We used the CrisisLexT6 dataset and constructed eleven source and target disaster pairs to experiment with. We showed that in general more source labeled data can produce better results, but performance does not change significantly after a certain amount, for example after 4000 instances (2000 on-topic and 2000 off-topic). If that amount of source labeled data is not available, our experiments show that even 500 source labeled instances can result in a relatively good classifier. This provides some insights into how much effort we should put into labeling data. Based on the analysis of performance variation with parameters, we recommend small values for δ (e.g., 0.001) to very slowly shift the weight from source to target and get good overall results. Furthermore, our study suggests that adding more than 1 instances from each class at each iteration of the algorithm (e.g., adding 5 or 10 instances from each class) benefits the final classifier. Finally, we showed that best overall results are obtained when fixing the shifting speed δ as 0.001, adding $k = 5$ instances from each class at each iteration, and running 300 iterations. This suggests that we can potentially use these parameter values as default in practice without sacrificing performance, and thus help disaster management and response teams prioritize the information that they need to more carefully analyze.

There are of course limitations to our work. While our results could contribute to a decrease in the amount of information that a human analyst needs to consider, by identifying tweets related to a disaster of interest, additional analysis is needed on other classification tasks, for example multi-class classification tasks, to understand how the algorithm behaviors generalize to different classification tasks. Thus, as part of future work, we plan to analyze the domain adaptation algorithm with self-training on more classification tasks. For example, we plan to consider the task of classifying disaster related tweets further into subcategories based on the user publishing the tweets or based on the tweet content - a tweet can be contributed by eyewitnesses, by victims or by news agents, etc., or a tweet can be about casualty, infrastructure, etc. As deep learning techniques have shown their potential in the context of social media data posted during emergencies, we plan to extend existing deep learning algorithms into unsupervised domain adaptation approaches, or supervised domain adaptation approaches that require a very small amount of target labeled data. Finally, we also plan to study how to choose a good source disaster for a particular target disaster, when we have different source disasters available. Alternatively, we plan to explore approaches for combining multiple source disasters.

ACKNOWLEDGMENTS

The computing for this project was performed on the Beocat Research Cluster at Kansas State University. We thank the National Science Foundation for support from grant CNS-1429316, which funded the cluster. We also thank the

National Science Foundation for support from the grants IIS-1526542 and CMMI-1541155 to Cornelia Caragea. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either express or implied, of the National Science Foundation. We also wish to thank our anonymous reviewers for their constructive comments.

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The Tweet Before the Storm: Assessing Risk Communicator Social Media Engagement During the Prodromal Phase – A Work in Progress

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ABSTRACT

Social media during the prodromal phase of the crisis lifecycle is critically understudied in the academic literature, as is the understanding of the role of engagement in these mediums by crisis responders and managers in helping the public prepare for a crisis event. This study analyzed 2.8 million tweets captured prior to the landfall of Hurricane Sandy. Risk communicators were identified and their tweets assessed for characteristics in the strategic use of Twitter and their levels of engagement with the general public. This work in progress provides a foundation for a longitudinal study analyzing future crisis events and measuring the growth of expertise and engagement in social media by crisis communicators.

Keywords

Risk communication, crisis response, social media, Twitter

INTRODUCTION

In 2011, in recognizing the need to establish protocols as social media became more integrated in emergency preparedness, response and recovery, the United States Department of Homeland Security (DHS) Science and Technology Directorate established a Virtual Social Media Working Group (VSMWG) to examine and define social media's role in crisis events and how government agencies may best utilize it as a resource. The results were three working papers released within the same year. The first paper, published in January 2012, "Social Media Strategy", sought to introduce social media as a strategic resource for use in in public safety, introduce best practice sand case studies for responders, and discuss the overall challenges of using these new collaborative technologies (DHS VSMWG, 2012b).

The second paper released in the same month, "Next Steps: Social Media for Emergency Response", provided detailed next steps to implementing the recommendations from the first paper (of Homeland Security, Directorate, Security Enterprise, & Responders Group, 2012). The final working paper, released September 2012, "First Responder Communities of Practice Virtual Social Media Working Group Community Engagement Guidance and Best Practices", advocated "pre-engagement" with the community to build trust and credibility, and to encourage "multi-directional" sharing of information (DHS VSMWG, 2012a). The purpose of these working papers are to advocate the implementation of social media, devise strategy, and encourage engagement across federally associated crisis responders, emergency managers, and their affiliates with the general public.

Five weeks after the release of the final working paper, Hurricane Sandy made landfall on the east coast of the US. Hurricane Sandy was a tropical cyclone that formed in the central Caribbean before moving west toward the mid-Atlantic coast and strengthening into a hurricane in late October 2012. By landfall in New York and New

Jersey, Sandy transitioned into a post-tropical cyclone coinciding with the period of the month where tides were highest, creating simultaneously, the largest storm surge and storm wind field on record, and the costliest hurricane in the United States to date (US Department of Commerce, NOAA, 2012).

Following the devastation of the hurricane, in June 2013, the DHS VSMWG released a fourth working paper, “Lessons Learned: Social Media and Hurricane Sandy”, identified the event as the largest social media participation for government agencies and crisis management partners, and further, identified technology, process, and policy gaps that require action. Though recognizing the event as an advancement of the use of social media in many agencies, the report concedes that more work needs to be done in communicating with the public, among other areas, and recognized the need to pre-deploy technological solutions for slow-onset events (U.S. Department of Homeland Security, 2013).

The American Red Cross, a non-governmental organization, issued their own findings in 2013 reporting advice and emotional support offered through social media, and while they tracked over 2 million posts prior, during, and after the storm, like the DHS report, they too, offered only a short anecdote of their efforts (Cross, 2013).

Despite discussing the need to use social media as a two-way communication channel, and discussing explicit plans for implementation, none of the four working group reports, or American Red Cross report, addresses how to assess the failure or success of social media use. If the goal of utilizing social media in emergency preparedness and response is to “connect with citizens during all phases of a crisis” and enact appropriate “behavioral change”, then digital response and engagement should be understood according to the different phases of an emergency, where then the development of evaluation of efforts used becomes increasingly more necessary (DHS VSMWG, 2012b).

Craig Fugate, director of the Federal Emergency Management Agency (FEMA) has a been an ardent advocate of social media and advises crisis responders and manager to use social media not just to push information out the public but to listen and engage through the various mediums (Stetler, 2012). Since the hurricane is recognized as a tipping-point for increased use of social media in crisis response community, using data garnered from the event, and parsed according the disaster phase. Deconstructing and describing the social media landscape by medium and by organization will provide a baseline by which future cases are compared and assessed. Such knowledge will help in the further establishment of protocols and standard to help improve the emergency management and crisis response use of social media.

To date little research has been performed on crisis responders’ use of social media by stage of crisis, nor with regards to engagement between responders and managers to the general public. In this paper, we look at tweets captured from the pre-crisis, or prodromal phase of Hurricane Sandy analyzing crisis responders as risk communicators and assessing their use frequency and engagement with the general public.

BACKGROUND

Emergency Preparedness

Emergency preparedness is the capability the inhabitants of a defined geographical area possess in effectively dealing with environmental threats and mitigating potential consequences with regards to physical and psychological health, and structural and technological systems (Tierney, Lindell, & Perry, 2001).

In Fiske’s four stages of the crisis, emergency preparedness takes place in the prodromal phase, where signals and alerts may occur, but before the actual onset of a crisis (Fiske & Taylor, 1991). Emergency preparedness involves the active cooperation between political jurisdictions and the potentially affected public where hazard assessment and risk reduction becomes are the main goals (Perry & Lindell, 2003).

Risk communication differs from crisis communication in that crisis communication addresses events as they happen or have happened, while risk communication addresses the time before an event becomes a crisis (Patric R. Spence, Kenneth A. Lachlan, Xialing Lin, 2015). Risk communication, as described by the National Research Council, is ‘‘an interactive process of exchange of information and opinion among individuals, groups, and institutions (Nelkin, 1989).’’ Risk communication also concerns itself with the public’s right to know about critical hazards and corresponding risks (Reynolds & Seeger, 2012).

For emergency preparedness, in lieu of in-person training, risk communication becomes paramount. In the traditional preparedness model, risk communication would occur via radio and television (Veil, Buehner, & Palenchar, 2011), however, with 76 percent of Americans on the Internet using social media (*Social Networking Use*, 2015), and 62 percent receiving their news from social media (Gottfried & Shearer, 2016), crisis responders and managers are well advised to integrate risk communication into their preparedness efforts (Merchant, Elmer, & Lurie, 2011).

Studying Social Media Pre-Crisis

Social media has been intensely studied in crisis response and management for over a decade. Since wikis and blogs were first used during Hurricane Katrina, we have seen social media emerge as a tool for knowledge management (Murphy & Jennex, 2006), community organization (Sutton, Palen, & Shklovski, 2008), situational awareness (McClendon & Robinson, 2012), rumor control (Mendoza, Poblete, & Castillo, 2010), and collaborative problem solving (Vieweg, Palen, Liu, Hughes, & Sutton, 2008).

Further, research has addressed the challenges of crisis responders using social distributed information in the form of information seeking behavior (Lachlan, Spence, & Lin, 2014), technical collection (Schulz & Probst, 2012), systems integration (Palen, Vieweg, & Anderson, 2010), and trust and credibility concerns prior, during, and after crisis events (Meier, 2011).

However, few studies focus on the prodromal or risk stage of impending events on social media. Though many crises, such as explosions or terrorist attacks, do not have a prodromal stage, many weather-related events such as hurricanes and snow storms, or spreading illnesses have a lag time between initial indications of the events potential onset and the actual onset.

Most research in the pre-crisis phase studied the use of social media as a detection method. Particularly in the case of Twitter, it has been studied as a way to detect conversation trends (Mathioudakis & Koudas, 2010), and emerging news stories (Petrović, Osborne, & Lavrenko, 2010), such as the emergency landing of US Airways Flight 1549 in the Hudson river (Landua, 2011). Twitter has also been studied as a soft-sensor for the signaling of potential impending crises such as earthquakes, where results were shown to have as much accuracy as traditional hard-sensors (Earle, Bowden, & Guy, 2011; Sakaki, Okazaki, & Matsuo, 2010), and as a tool to enhance situational awareness before a crisis has occurred (Crooks, Croitoru, Stefanidis, & Radzikowski, n.d.).

Two studies specifically looked at information in prodromal stage. Spence et al looked at the type of information on Twitter prior to Hurricane Sandy and discovered the quality of information tapers before crisis onset (Patric R. Spence, Kenneth A. Lachlan, Xialing Lin, 2015). A follow-on study by Lachlan et al, using the same data set, demonstrated that while Twitter is used to express perception of risk, how and why varies greatly by gender and demographic (Patric R. Spence, Kenneth A. Lachlan, Xialing Lin, 2015).

At issue with both these studies is that collection times were limited resulting in garnering 27,259 tweets as a macro sample and only 1700 in a micro sample being analyzed, during an event where over 20 millions tweets were generated (Twitter, 2012). Further, these studies only utilized the hashtag “sandy” when other popular terms were trending. Lastly, only one study looked specifically at what they deemed to be crisis responders, the National Oceanic and Atmospheric Administration (NOAA) and the Centers for Disease Control (CDC), when neither organization would be responsible for direct emergency management, and not necessarily considered the typical risk communicators the general public would look to prior to a crisis.

Defining Engagement

Engagement and crisis response on social media is a similarly under-studied area. Researchers assert many crises may be avoidable through proactive listening and engagement on behalf of crisis responders (Veil et al., 2011). Not only though the promotion of preventative action, but by providing emotional support as well. Coombs and Holladay discovered the type of support the public receives across all channels of communication can affect the public’s attitude towards crisis response strategies (Coombs & Holladay, 2005).

For organizations that have adopted social media as a part of a communications strategy, many have policies restricting and limiting its use as a one-way push of communication rather than as an online dialogue (Baron & Philbin, 2009). For those using social media in a dialogic fashion, research suggests that this enhances community engagement, which in turn builds trust and social capital in the crisis communicators (Yang, Kang, & Johnson, 2010).

According to Twitter, engagement is defined as the “total number of times a user interacted with a Tweet. Clicks anywhere on the Tweet, including Retweets, replies, follows, likes, links, cards, hashtags, embedded media, username, profile photo, or Tweet expansion (“Tweet Activity Dashboard,” 2016).” Another metric, the engagement rate, is the number of engagements divided by the number of impressions – the impressions being the number of times a Twitter user sees a tweet in their timeline or search results.

Thus, if specific preparations can help mitigate or offset potentially devastating effects of a crisis, and if social media is becoming the preferred method of Americans receiving news regarding impending crises, and if engagement is essential to building cooperation and trust during crisis events:

RQ1: With what frequency did risk communicators communicate during the prodromal phase of Hurricane Sandy?

RQ2: To what level did risk communicators engage with the general public during the prodromal stage of Hurricane Sandy?

RQ3: What does the level of frequency and engagement infer regarding risk communicators' overall use of Twitter during this event?

RQ4: How might assessing frequency and engagement inform the future practices of risk communicators?

DATA AND METHODS

From October 26, when the states of New York, Maryland, Washington, Pennsylvania, North Carolina, and Maine declared a state of emergency after Sandy passed over the Bahamas in the Caribbean (CNN Library, 2015), thru October 29, 2012, prior to Sandy's landfall in New York and New Jersey, 2.8 million tweets were captured referencing the top trending words: Sandy, Hurricane, and Hurricane Sandy (CNN Library, 2015; Twitter, 2012). From this data set, 192 persons and organizations responsible for emergency or humanitarian response, or communicating information regarding crisis and risk were targeted for additional analysis resulting in a sample of 1,895 tweets available for further analysis.

The organizations identified included Federal Emergency Management Agency (FEMA) and the American Red Cross, the National Weather Service, the National Oceanic and Atmospheric Administration (NOAA), and their various regional offices, the American Red Cross and its many offshoots, the National Weather Service, state and local emergency management, city mayors, state governors, police and fire departments, the United State Coast Guard, and the Whitehouse. Officials, such as FEMA Director Craig Fugate, Newark, New Jersey Mayor Cory Booker, and other persons identified as working or affiliated with the above referenced organizations.

These organizations and persons were first coded by class and by mission. Class is determined by whether the Twitter account was federal, state, city, or non-governmental organization. Mission was determined by the type of activity the person or organization is responsible for: emergency management, humanitarian relief, security, governance, or weather.

Each tweet was coded for the absence or presence of a hyperlink, the response to a private person's account, a government or non-governmental organization, or a media or business account. Likewise, the data was coded for retweets to previously mentioned account types. Further, data was coded trending hashtags (sandy, hurricane, hurricanesandy, Frankenstorm), off-topic hashtags, or tweets that contained plain text without any of the previous mentioned elements.

Since the internal metrics of risk communicators was unavailable for study, for the sake of this research, a two-tier approach to publicly available information regarding engagement was used.

The first tier, active engagement is defined as the direct reply (or '@') from a risk communicator to another person or organization Twitter account, or a Retweet (or 'RT') from a risk communication to another person or organization. The second-tier, or passive engagement reflects the number of times a risk communicator liked or favorited (reflected on Twitter as heart-shaped symbol).

A single researcher coded the 1895 tweets of interest for this study. However, two assistants were trained on the same coding schematics and re-coded the data. As the analysis was performed on binary variables, percent agreement was performed and a coefficient of .95 was achieved for intercoder reliability. For communication studies, Lombard et al recommend a coefficient of .90 or higher (Lombard, Snyder-duch, & Bracken, 2002), fully .10 above the standard normally employed (Neuendorf, 2002).

INITIAL FINDINGS

Out of the 2.8 million tweets collected from October 26 to October 29, 1895 tweets from 191 persons or organizations affiliated with emergency response or crisis management were identified and analyzed. These tweets constitute .0007 percent of the total tweets captured. Of the 191 persons or organizations, this amounts to a daily average of 2.47 tweets, and an average of 9.92 tweets overall. Of the 1895 tweets analyzed, 79 percent occurred on 27 and 28 October.

The range of tweets sent during this time is from 1 to 265 (see Table 1). Thirty-three percent of the tweets fall within the 21 to 50 tweet range and were sent by 10 percent of the organizations. Four organizations, or 2 percent overall, sent 28 percent of the tweets. However, of these four organizations, two of the entities' tweets are automatically generated. Sixty-three percent of the organizations ranged from 1 to 5 total tweets prior to landfall of the hurricane.

Table 1. Tweets range and percentage of analyzed tweets.

Tweet Range	1	2-5	6-10	11-20	21-50	>50
# Organizations	55	64	31	18	20	4
% Organizations	0.29	0.34	0.16	0.09	0.10	0.02
# Tweets	55	197	235	265	620	523
% All Tweets	0.03	0.10	0.12	0.14	0.33	0.28

Of the 1,895 tweets analyzed, 63 percent inserted hyperlinks to information on preparedness or news updates (see Table 2). Sixty-five percent of tweets also contained the hashtags: Sandy, Hurricane, or HurricaneSandy, either alone or mixed with other hashtags, however, 168 tweets, or 9 percent, contained hashtags that were either self-branded or attributable to topics outside of the hurricane. A low percentage of tweets contained plain text, that is, posts made with no links, hashtags, hyperlinks, replies or retweets.

Of the 192 organizations, 34 percent of their tweets were retweets (RT) of private person, government or non-governmental organizations, and media or business (see Table 2). Direct replies (@) were limited to just 14 percent to the same entities.

Table 2. Elemental breakdown of analyzed tweets.

Tweets Containing:	Number	% Org Tweets
Hyperlink	1199	0.63
@ Private Person	52	0.03
@Government/NGO	158	0.08
@Media/Other	54	0.03
RT Government/NGO	484	0.26
RT Media/Other	114	0.06
RT Private Person	37	0.02
Plain Content	51	0.03
Trending/Mix #	1234	0.65
Off-Topic #	168	0.09

In categorizing the tweets by class, accounts through the federal government posted 751 tweets, 40 percent (see Table 3). State accounts closely follow with 34 percent. When looking at the subset by mission, governance accounts posted the most tweets, followed by weather and closely followed by emergency management. Law enforcement posted the least amount of tweets with 2 captured during the prodromal period.

Table 3. Tweets posted by class and mission.

Class	Emergency	Governance	Humanitarian	Law	Security	Weather	Total
NGO			337				337
FEDERAL	239	3			51	458	751
STATE	143	451		2	43		639
CITY	57	111					168
Total	**439**	**565**	**337**	**2**	**94**	**458**	**1895**

Overall, most communicators recognized the 140 character limitation and used external links to connect people to more information. The American Red Cross in particular, regularly encouraged the public to download a special smartphone app for Hurricane Sandy in order to help people prepare for the storm, receive alerts, and monitor places of interest (see Figure1).

Figure 1. @redcrossny encouraging the public to download a special app for Hurricane Sandy.

By class, federal and state accounts are closely matched, with the majority of federal posts coming from weather-related accounts, while the majority of state posts coming from governance-related handles.

For NGOs, despite the proliferation of Red Cross handles, and the media campaign to promote their Hurricane Sandy preparation app for mobile phones, there were only 337 tweets across 59 various Red Cross affiliated accounts. Four accounts, Central Massachusetts, New York, Philadelphia, and the main account, contributed to the bulk of the tweets, a logical occurrence given the proximity of these areas to the projected landfall of the hurricane.

By class, law enforcement had the least amount posts, only 2 during the prodromal stage, however this is not surprising given that, at least in New York City, the majority of precincts did not even have Twitter accounts until April 2014. This is lack of activity and absence of account is of less concern considering that law enforcement tends to be reactive presence in crisis management as opposed to proactive.

In light of the fact that more than 20 million tweets were posted before, during, and after the event (Twitter, 2012), the number of tweets posted by communicators, even considering the retweets of their posts by the general public, is considerably less than one percent of the overall tweets. Further, of the 192 persons and organizations identified, twenty accounts, 10 percent, were responsible for 33 percent of the tweets. Of the top tweeters within this group, there were 4 organizations that posted over 50 tweets during this pre-crisis period, and two of these accounts send automated tweets posting weather updates.

Inconsistent use of hashtags has long been a problem for those new or unfamiliar with Twitter (Potts, Jones, Seitzinger, & Harrison, 2011). Organizations will often self-promote through hashtagging, but when a trending topic has been established, using a popular hashtag makes it easier to search for information on a specific topic, and if a person or organization does not hashtag accordingly, they risk getting lost in the stream of tweets.

As Sandy fluctuated between a low-grade hurricane, a winter storm, and a tropical storm, the posts from the National Weather Service (@National_WX) general twitter account reflected the change. However, without referencing "Sandy", in either plain text or via hashtag, only 13 of their 72 tweets are searchable by the trending term. The National Weather Service satellite office for Lake Charles, Louisiana (@NWS_LCH) posted 112 automated tweets prior to landfall, but still mentioned Sandy in all but 4 posts. These 4 posts still contained the "hurricane" keeping the post on topic. These two examples exhibit the benefits and downfalls of automation. With forethought and planning, automation has the potential to be relevant to the social conversation at hand, or potentially excluded.

Overall, with such low frequency of posting during the prodromal stage of the crisis, risk communicators can ill-afford having 9 percent of their tweets lost in the social stream with off-topic hashtags or plain text that does not strategically keep their tweets in the public conversation.

Other forms of more direct engagement with the general public were extremely limited. Direct engagement by either responding to a tweet of a private person or retweeting their post constituted 5 percent of all risk communicator tweets. Most persons and organizations responded or retweeted like entities (29 percent) or media and businesses (14 percent). Responding directly to or retweeting like entities has the potential for creating an echo-chamber effect, but in this context of an impending crisis, it would likely be seen as trusted advice from recognizable sources, and given the many permutations of FEMA, the National Weather Service, and the American Red Cross, consistency of message is key and may be more important in this case.

Figure 1. Delaware Governor, Jack Markell, was prolific in direct response prior to Hurricane Sandy.

Official accounts of public figures posted the most replies to the general public. The most engaged during this event was the account of Governor Markell of Delaware, who directly responded to 25 tweets out of 35 prior to landfall, answering questions, and updating and correcting information (see Figure 1). Cory Booker, former mayor of Newark, New Jersey, also replied to numerous private persons during this time.

According to the final lessons learned from the DHS VSMWG, from 22 October thru landfall, the Red Cross tagged 10,447 tweets and Facebook posts for "further consideration", and following the landfall, had responded to 2,386 of the posts [39]. Communication with the American Red Cross did not yield information regarding the amount of time between tagging a tweet for consideration and when the response occurred.

Despite claims of having responded to thousands of social media posts [4], during the prodromal phase, the Red Cross responded to 9 tweets in the data set, 2 of which were a thank you to celebrities for acknowledging them in their own tweets. This suggests either a greater emphasis is placed on other phases of the emergency, or a greater emphasis was placed on Facebook during the prodromal phase. This can be problematic when people are searching for preventive solutions, and also given the fact that despite the phase of the emergency, certain social media platforms serve increasingly narrower demographic groups [7]. However, in this same tweet set, the 31 tweets the Red Cross posted were retweeted 2133 times and favorited 215. FEMA responded to 1 question during this time frame, but of their 26 tweets, they were retweeted 4605 times and favorited 397. While one direct response may not meet the spirit of successful engagement, it is unclear whether a metrics based approach suffices as no definition for the mandate of "successful engagement" is provided within the DHS VSMWG working papers.

DISCUSSION

Previous research suggests that risk communicators should advise specific behavior with a "degree of alarm that is enough to motivate but not paralyze" and "lead audiences to make ideal decisions concerning the protection of life, health, and property(Lachlan, et al., 2014)." This type of communication not only requires a well-crafted message, but technically requires the preferred medium of communication be used to its maximum potential, and that communicators engage rather than broadcast in order to help empower citizens (Seeger, 2002), particularly since 62 percent of Internet users now receive news through social media (Gottfried and Shearer, 2016).

In general, given the large number of social media adoption by the US general public in 2012, Hurricane Sandy appears to be a missed opportunity for risk communicators to engage, and largely demonstrates a low level of social media savvy exhibited by most organizations studied in this work. DHS's lack of assessment development and benchmarking prior to the event means there is no standard by which to measure the success or the failure of risk communicators. Even outside of the government structure, when contacted about practices in internal assessment and benchmarking on their social media use, the American Red Cross referred back to simple metrics provided by Twitter and Facebook with indication of whether they assess themselves longitudinally.

As social media increasingly becomes the way that news and information is disseminated across the general public, and given the number of social media and closed networking sites that have risen in use since 2012 (i.e. Snapchat, Instagram, Pinterest, etc.), they need for gauging effective use across channels becomes ever more important. To maximize the potential of any medium, higher instances of direct engagement may be required by emergency managers and risk communicators to become proactive as opposed to only reactive in the time leading up crisis events.

Developing frameworks for assessment and comparing assessments of crisis events over time will help risk communicators, both governmental and NGO alike, to develop better practices and protocols. One cannot determine the success or failure is one does not performs the simple act of counting and establishing a baseline for minimum performance. Further, emergency managers should consider the value of engagement in promoting behavior that either prevents or mitigates the effects slow moving disasters may have on the affected public. Crisis events that can be forecasted, even with as little as 24 hour notice, provide a window of opportunity for the public to respond appropriately, provided skilled emergency professionals place equal emphasis on proper communication across all phases of the event.

LIMITATIONS AND FUTURE WORK

The data collected for this study was limited to those tweets containing the three most popular hashtags used prior and during the onset of the storm. Additionally, Twitter is known to limit full access to data, even within it own search API, thus there is no way of knowing how many tweets failed to be captured.

Twitter is one of many popular social media platforms used in the United States, hence, this study does not account for engagement levels in Facebook, Instagram, or other social media platforms.

Further, the analysis presented here reflects one moment in time, prior to crisis onset, in 2012. This research does not account for advancements in access and use of social media across crisis response and humanitarian organizations since that time.

As this study only focused on the use of Twitter during Hurricane Sandy, an additional study on the use of Facebook during this time frame would be useful in providing a more well-rounded assessment.

Using this study as a baseline, future research will involve the data capture of tweets and Facebook posts during another slow moving, impending event such as a hurricane or snowstorm. Using 2012 as a baseline, the maturity of use among crisis and risk communicators may be assessed.

Lastly, an additional study is required to assess information seeking behavior in the form of direct question posting. Is the public actually asking questions in this medium? In active or passive information seeking, identifying whether the general public asks for information in this medium or only searches Twitter for information regarding preparation and action would address this question.

ACKNOWLEDGMENTS

This study was funded in part by the Department of Energy Visiting Faculty Program at Pacific Northwest National Laboratory. Special thanks to Anthony Kim of Samsung Research for the data set used in this research.

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Linking up the last mile: how humanitarian power relations shape community e-resilience

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ABSTRACT

In this paper we present a qualitative, social network based, power analysis of relief and recovery efforts in the aftermath of the 2015 earthquakes in Nepal. We examine how the interplay between humanitarian power relations and e-resilience influenced communities' ability to respond to the destruction brought about by the disaster. We focus in particular on how power dynamics affect online spaces and interactions at the hyper local level (or 'the last mile'). We explain how civic technology initiatives are affected by these power relationships and show how their efforts may reinforce social inequalities – or be sidelined – if power dynamics are not taken into consideration. However, on the basis of a case study based power analysis, we show that when civic technology initiatives do strategically engage with these dynamics, they have the potential to alter harmful power relations that limit community e-resilience.

Keywords

Power relations, e-resilience, humanitarian disaster, social capital, Nepal.

INTRODUCTION

One of the core questions that underpins disaster research is why some communities are able to adapt and recover from the impacts of external and internal shocks, whereas others struggle (Van der Vegt et al., 2015). E-resilience refers to the ICT based practices that enable communities to respond and adapt in times of disaster (Ospina & Heeks, 2016). In recent years, Web 2.0 platforms have increasingly been used by civic technology activists in an effort to empower communities and responders in times of disaster. Civic technologies are applications run on open data platforms that aim to improve (public) services through citizen participation. In disaster settings, digital humanitarians have (for example) used crowdsourcing and social media scraping in order to create interactive online maps with crisis reports (e.g. Meier, 2015). The ability to access and share information is central to organizing an effective response (Van de Walle & Comes 2015). Indeed, e-resilience is an important enabler of collective action, for it enables communities to create (online) spaces for knowledge sharing and coordination. Furthermore, ICT infrastructure supports the ties communities have to these spaces – as well as to geographically remote connections.

Indeed, connectivity is an important marker of e-resilience. In disaster settings, as elsewhere, e-resilience is brought about through the interaction between human agents and material infrastructures and devices. Given the important role of human actors it is worth analyzing the interplay between e-resilience and relationships of power. As highlighted by Comes and Adrot (2016), the impact of power relations on information sharing and collective action in disaster settings has to date received little attention. Civic technology platforms designed for disaster settings generally aim to empower affected citizens and humanitarian professionals by providing a platform where communities and humanitarian professionals can share information and coordinate. In this paper we will show that technology driven social empowerment is never just the product of technology itself but the product of the interplay between technology and social power relations. We contend that power relations and technology are mutually constitutive: power relations shape technology and technology shapes power relations (Williams & Egde, 1996).

Most humanitarian civ tec platforms tend to present themselves as 'a-political technical solutions' and do not critically reflect on the power relations that shaped their design or the power relations that mark the setting where they will be rolled out. However, by failing to take into account how power relations shape the interactions in their online spaces, civ tech platforms risk reinforcing social inequalities. As we have argued elsewhere, the unintended consequence of this may be that those who are most in need benefit the least from civ tech initiatives (Mulder et al., 2016). Indeed, humanitarian civ tech initiatives that do not pay adequate attention to power relations may fail to achieve one of the humanitarian core objectives: reaching those most in need. In this paper we will argue that there is a strong interplay between power relations and communication networks (in both the infrastructural sense and as relating to human interactions). As others have pointed out, the usage of ICTs in crisis settings is linked to the influence actors have over an emergency response as a result of their network position (Hu & Kapucu, 2014). In this paper we extend this argument by looking at the different levels, forms and spaces (Gaventa, 2004) through which networked power relations are enacted at the last mile of a humanitarian response (i.e. at the hyper local level) – and the impact this has on community resilience. Gaventa's power cube (2004), discussed below, shows how these loci and forms of power can interlink. The cube is intended to help actors identify and analyze how power relations affect their specific projects and objectives and suggests strategies for repositioning. In this paper we add to the ISCRAM debate on the last mile by integrating Gaventa's approach to analyzing power with a focus on information networks. Using this approach we explore the interplays between power relations, connectivity and e-resilience in a humanitarian setting.

The extent to which communities are able to help themselves – and attract external assistance during a crisis – is greatly influenced by the quality and quantity of their relationships with each other and their connections to the rest of the world. Indeed, social capital is inherently relational: it resides in the links and connections between individuals and groups. Social capital refers to communities' ability to share assets (such as information) and work collectively towards a specific end (e.g. Putnam, 2000). Given its importance, control over (access to) information and communication flows is often an important locus of the power struggle between established institutions and those who seek to challenge them (Castells, 2011; 2013). It is worth noting that in a humanitarian setting disadvantaged communities tend to be digitally underprivileged in multiple intersecting ways. They tend to have less access to internet enabled devices, are trapped behind linguistic and literacy divides and depend on sparse and vulnerable ICT infrastructures. Indeed, the co-evolution of communities and their environments can give rise to deeply embedded societal inequalities and structural vulnerabilities (Oliver-Smith & Hoffman, 2002). In terms of connectivity, it often gives rise to network structures whereby less powerful groups have fewer and less reliable ties to the rest of society whereas more powerful groups have a greater number of more dependable ties that link them up. In this paper we will show how the interplay between the destructive force of a disaster and the evolved inequalities and power relations that mark a humanitarian setting can result in the least resilient parts of information networks being hit hardest – and information flows (and hence power) being concentrated into the hands of elites. We also discuss how civ tec initiatives could be used to counteract this process.

In this paper we present a qualitative, social network based, power analysis of relief and recovery efforts in the aftermath of the 2015 earthquakes in Nepal. We focus in particular on the interplay between power dynamics at the last mile and in the 'claimed' and 'invited' spaces civ tech initiatives helped create. The latter refers to spaces (or opportunities) for community participation and interaction created by formal institutions and the former refers to spaces (or opportunities) created by grassroots initiatives and communities (Gaventa, 2004). The purpose of this paper is to provide an example of how a power analysis could help civ tech initiatives strategically position themselves in a humanitarian setting so as to genuinely boost e-resilience at the last mile and empower those most in need. Looking at the power relationships that mark affected communities, humanitarian responders and civ tech initiatives, this paper addresses the following research question: *How did the interplay between power relations and e-resilience influence access to information and knowledge sharing in the aftermath of the 2015 earthquakes in Nepal?*

CIVIC TECHNOLOGIES AND E-RESILIENCE

The importance of maximizing the resilience of local response systems – as opposed to forging standardized responses in a top down manner – has been recognized for over thirty years (e.g. Drabek,1983). It is impractical to prepare standardized top down response scenarios for all potential hazards at the hyper local level. As such, fostering the ability of communities at the last mile to respond and adapt with agility to the impact of shocks is more fruitful. ICT enabled connectivity has the potential to boost local response capacity at times of disaster for it enables communities to effectively leverage their social capital. After all, assets such as information and knowledge can only be used for effective collective action in times of disaster when they are shared and combined. Taking a network perspective, the extent to which nodes are connected to each other within clusters and the extent to which clusters are connected to each other across a humanitarian response, greatly influence the resilience of the social structure as a whole in the aftermath of a disaster. Resilient social systems tend to be marked by strong ties at cluster level that are rich in "bonding social capital" (Putnam 2000). This means that people are able to make legitimate claims on the time and resources of other members of their cluster by appealing to people's their sense of group loyalty. Furthermore, resilient systems tend to be marked by multiple direct and indirect ties between disparate clusters. The reason for this is that organizing relief at times of disaster requires a high level – and range - of resources and skills. Isolated clusters tend to lack diversity and do not enable people to access resources or skills beyond what they have already. Access to external networks, so called 'bridging social capital' (Putnam, 2000) is essential for enabling effective cross-network collaboration. The key thing to note here is that disadvantaged groups tend to rely on ICT infrastructures that are sparser and more vulnerable to the impact of a disaster. Small remote rural villages in the mountains, for example, may depend on one core power generator and become cut off from mobile and wifi networks if this power generator gets destroyed. As such, the least powerful in society are often most likely to become disconnected when a crisis occurs. This means that these disadvantaged groups are less able to share information – or coordinate – with geographically remote nodes in their networks. As a result, they are less resilient and less able to respond effectively in times of disaster. Unreliable connectivity also increases vulnerability at 'the last mile' in another way: poorly connected (rural) communities tend to respond too late to hazard warnings (e.g. LIRNE Asia, 2008; Singh Bedi, 2006).

Digital inequalities – such as unequal access to reliable ICT infrastructures - map strongly onto other inequalities. On the eve of the earthquakes in Nepal in 2015, 85% of rural Nepalis had never used social media or the internet. They depended on more traditional ICTs, such as telephones, radios and televisions (Girard, 2015). 50% of their urban counterparts, by contrast, used social media on a regular basis (ibid). Digital inequalities contribute greatly to the fact that the least resilient parts of a society are also the least visible in digital data sets. The importance of visibility at times of disaster cannot be overstated. In the immediate aftermath of the earthquakes in Nepal, traditional and social media initially 'overlooked' badly hit rural communities in the worst hit districts, focusing instead on the damage suffered in the Kathmandu valley area. The crisis crowdsourcing initiative Quakemap, for example, generated a data set that was strongly skewed towards this area, in spite of the platforms' best efforts to lower barriers to participation. The systemic power imbalances between urban and rural Nepal meant that Kathmanduites were relatively well-connected to traditional and social media based information networks – and able to access online created spaces (such as civ tech platforms or Facebook groups) whereas villagers in the mountain areas of Gorkha (the epicenter) were not. As a result of the over-representation of the Kathmandu valley in traditional and social media, formal responders, such as government bodies, (I)NGOs and IOs, initially focused their aid efforts in this area, even though other districts had been hit much harder.

As such, because many civ tech initiatives had not strategically addressed the power imbalances that shaped access to and participation in their online resilience boosting spaces, their efforts did little to address the weakest point in the humanitarian information flows: linking up the last mile. Furthermore, because their skewed data sets reflected the digital divides that mark Nepal, their efforts may (unintentionally) have reinforced existing inequalities as their open data pointed responders to the better connected communities rather than those who were most in need (e.g. Mulder, 2016; Crutcher & Zook, 2009; Elwood, 2007; Goodchild, 2007).

FOCUS AND METHODS

This paper is based on a power analysis of the socio-technical relationships that marked rural Nepal at the hyper local level (or 'last mile') in the aftermath of the 2015 earthquakes in Nepal. Our focus is on the interplay between power and information networks. We treat these networks as both social and material in nature. Indeed, we regard these two aspects as mutually constitutive. In telecommunications, the term "network" refers to the connections between computers and other electronic devices that enable them to exchange data. A "social network", by contrast, is often defined as the connections between social agents that allow them to exchange information (e.g. Burt, 2000) and work collectively towards a specific end (e.g. Putnam, 2000). However, in today's hyper-connected world, or what Castells' (2011) has termed the *Network Society*, these two types of structures are deeply interconnected. Commonly-used technologies play a central role in shaping the interactions and flows that give rise to social network structures (e.g. Leonardi, 2011). ICT networks influence which social agents can exchange information and work together.

Conversely, social agents play a central part in determining what shape ICT networks will have. Ties between agents are often actualized by ties between devices. This holds across the globe. Even communities living in remote villages in the Himalayas have been connected to the wider world via radio and telephones for decades. Getting information and other resources to such communities in times of disaster is commonly referred to by humanitarian professionals as "the last mile challenge". In telecommunications, the term "the last mile" is widely used to refer to the final leg of ICT networks: the last bit of the chain that reaches the premises of end-users. As such, the debate around linking up the last mile often centers on technical problems or the absence of communication infrastructure at the hyper local level. However, whether and how "the last mile" gets linked up with is also heavily influenced by social factors. Furthermore, the impact connectivity has on a community's ability to respond effectively in times of disaster is also shaped to a very large extent by the power relations that mark that particular community. As such, in this paper we present a power analysis of the socio-material last leg of information networks, so as to explain the impact of power on e-resilience and people's ability to organize an effective response. Whilst our focus is on the interplay between power and networks, we do not use classical social network analysis (SNA) in this paper. In our case study we describe power relations that generally mark rural Nepal at the hyper local level from a social network perspective, but do not present a SNA graph of one specific village showing the actual nodes and ties that mark that unique setting. We have chosen a qualitative approach, as this allows for detailed and in-depth investigations of network relations; the processes involved; how and why networks change; as well as to what extent they facilitate collective action (Jack, 2008).

This paper is based on research carried out by a team of researchers – including the authors of this paper - in the aftermath of the 2015 earthquakes (Wolbers et al., 2016; Baharmand et al., 2016). It draws on insights gained during three months of fieldwork (observations and open interviews) and a review of the academic literature, practitioners' texts and social and traditional media. Purposive sampling was used to select respondents. These individuals were identified and contacted through social media (especially LinkedIn and Facebook) and through introductions by existing contacts in the field. The findings presented in this paper are the product of an iterative analysis, whereby the researchers continuously moved between data collection, data coding and the academic and professional literature. As such, findings have been triangulated by going back to respondents and checking them against the existing literature (Strauss & Corbin, 1994). In the analysis presented here we focus on the relational information about the interplay between power and e-resilience found in these sources. Our power analysis explores the different dimensions of power, as usefully summarized in Gaventa's power cube (see figure 1, below).

Different scholars have taken different approaches to power. Broadly speaking, these approaches can be categorized as either 'episodic' or 'systemic' (Fleming & Spicer, 2014). Whereas the former refers to action-based power held by actors, the latter refers to more pervasive forms of power that are embodied in a web of relationships and discourses that affect everyone (Gaventa, 2004). Examples of episodic power are the ability of some actors to coerce or manipulate other actors. Examples of systemic power are the ability to manufacture consent and shape people's beliefs. Gaventa distinguishes between visible power (e.g. the power to coerce); hidden power (e.g. the power to manipulate); and invisible power (e.g. the power to shape people's beliefs). The latter includes the power of discourse, i.e. the power to shape subconscious attitudes and behavior through the repeated use of tropes, formal definitions, imagery, architecture and so on (Foucault, 1975). Gaventa refers to visible, hidden and invisible power as different 'forms' of power. These different forms of power play out at different levels. In a humanitarian setting, the 'global' level is the international community; the 'national' level refers to actors working at the national level, generally from the capital city; and the 'local' level refers to all action that takes place at the sub-national level. Gaventa points out that these different levels are all interlinked and all affect each other, stressing the importance of initiatives that link across the different levels. Online spaces tend to fall outside the global, national and local divide.

Spaces like this have been called 'glocal' (Harcourt & Escobar, 2002) and hence constitute opportunities for communities to reposition themselves and to some extent transcend local power relationships. They also provide formal responders with ways of reaching down and facilitating a better vertical integration of the response. The final side of Gaventa's power cube refers to 'spaces'. These are locations or opportunities for interaction, such as knowledge sharing or coordination. These spaces are located at (or across) specific levels and are marked by the interplay between specific forms of power. A 'closed' space refers to decision-making by power holders behind closed doors. An 'invited' space refers to an opportunity - created by formal institutions - for communities to contribute to decision making, albeit not on an equal footing. Finally, claimed or created spaces refer to spaces or opportunities communities or grassroots initiatives have created for themselves in order to voice their views and coordinate their actions. Figure 1 below shows how the different axis of power interlink. The arrows suggest ways initiatives can strategically position – or reposition themselves in order to address the specific power dynamics that undermine their social objectives.

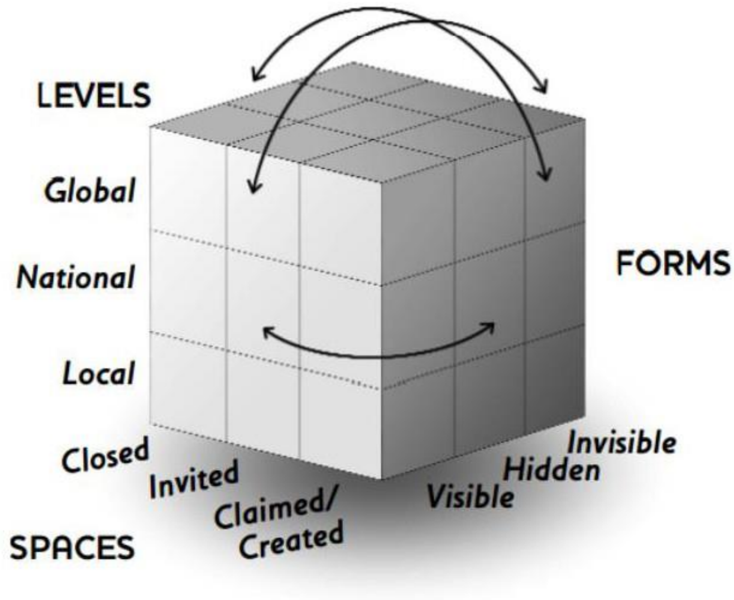

Figure 1: The Power Cube (Gaventa, 2004).

CASE STUDY: A POWER ANALYSIS OF E-RESILIENCE AT THE LAST MILE

In the spring of 2015, Nepal was hit by two large earthquakes, which occurred 17 days apart. As a result, close to 9000 people died and a half a million properties were destroyed. In response, a large scale humanitarian operation was launched in which national and international actors worked alongside each other (and sometimes together) in aid and relief projects. In this case study we address this paper's research question by describing how the interplay between power relations and e-resilience influenced access to information and knowledge sharing in the aftermath of the earthquakes. The first thing to note is that the power relations that shaped the interactions that marked the humanitarian response played out over different levels, from the global, to the national, to the local and to the glocal. Looking at ties between affected communities, government authorities, NGOs and grassroots initiatives in Nepal, we see that the social network structure that linked up the different levels was markedly layered. Whilst network clusters at the (inter)national level were connected to each other through numerous redundant ties, they were less well connected to clusters below them (at district level) and generally poorly connected to the clusters at the lowest levels (village and ward). In other words, due to the layered nature of the response, power relations at higher levels only interacted with those at the lowest level at a few key points. These points were occupied by actors who consequently had a lot of influence over access to higher level networks and spaces.

Zooming in to the hyper local level, we see how power relations played out in different forms. Nepali society is marked by strong connections between individuals from similar backgrounds. As such, community networks tend to be rich in *bonding social capital*, (explained above) which enables people to work together effectively with other members in their network. Geography is another important variable that shapes community networks: most rural Nepalis, even those in the remotest villages, are closely connected to people in Kathmandu or abroad. As a result of rural economic decline due to the civil war (1996-2006) Kathmandu has doubled in size since 2000. Furthermore, today over 2 million Nepalis (7% of the total population) work abroad in places like Malaysia, Qatar and the Gulf States. As such, Nepali 'local communities' stretch over all levels of a humanitarian response: from the local to the national to the global. Rural communities have depended on 'traditional' ICTs (such as telephones and radios) for decades in order to maintain social relationships with their geographically dispersed close ties. However, their economic marginality is reflected by the ICT network infrastructures that mark Nepal. The infrastructures they depend on are sparse, less well maintained and hence more vulnerable to the impact of shocks. The impact of the quakes in 2015 on this vulnerable set up inevitably resulted in high levels of destruction, limiting the ability of many rural households to effectively involve distant husbands and sons in family efforts to respond and cope with the impact of the disaster. It also limited their ability to engage with external information and resource networks.

Not all social groups within rural communities were equally affected by the earthquakes and the resulting destruction of ICT infrastructure and devices. Historic power imbalances have given rise to deeply embedded socio-economic inequalities in rural Nepal that continue to shape people's resilience to this day. On the eve of the disaster, low caste groups, for example, tended to live in in more hazardous rural locations marked by poor ICT infrastructure. Upper caste groups (i.e. Brahman / Chhetri)[1] by contrast, were significantly more likely to be among the rural elites and live in the safer, more connected parts of their villages (in better constructed houses, perhaps even with their own back-up power generators). As such, low caste groups were significantly more likely to become disconnected as a result of the earthquake than upper caste groups. There are other socio-economic inequalities that mark rural Nepal, such as those based around ethnicity, gender, age and able-bodiedness, to name but a few. The ability of people to respond and adapt to the impact of the quakes was heavily shaped by the interplay between power and these social identity markers. Upper caste groups, for example, frequently held official positions of authority, working as local bureaucrats or local level political party leaders. Many also held power informally, such as community leaders or locally respected men (often called 'intellectuals'). Rural elites tended to benefit from vertical networks and positions of influence. As such, if they did become disconnected, they were able to call upon their connections and resources to maintain or restore their connectivity relatively quickly. The ability of local elites to stay connected is an example of action-based power, also called 'visible power' (Gaventa, 2004), or 'coercion' (Fleming & Spicer, 2014). Coercive power is based on actor's formal position (Weber, 1947), personality (House, 1968) and possession of valuable resources (Pfeffer & Salanick, 1974).

Thanks to their vertical networks and positions of influence, rural elites hold an established role in connecting their communities to external information and resources. Indeed, their vertical networks constitute vital bridging social capital for their communities. However, the unequal impact of the quakes on the connectivity of different rural socio-economic groups meant that control over information flows became even more concentrated into their hands. Their broker position between their rural communities and the wider world gave them the power to influence what information was shared and how it was presented. As such, it gave them the power to manipulate; another example of action-based or visible power (Fleming & Spicer, 2014). They were able to mobilize people's biases (Alexander, 1979) and shape expectations (Gouldner, 1970). Many Nepalis have very low expectations about their government and brokers can easily mobilize this bias, confirming people's beliefs that little or no help will be provided by the central government. By doing so, the brokers can strengthen people's perception of dependence on them (the local power holders). This 'hidden power' allows brokers to control politics backstage (Gaventa, 2004). As such, the uneven destruction of ICT infrastructure strengthened the ability of local elites' power to coerce and manipulate. This does not mean that local elites did not act in the best interest of their communities. However, with few alternative means of accessing information and resources local communities were not empowered to hold these men to account.

There are more long-term, systemic and 'invisible' forms of power that contribute to the influence of local elites over communities at the hyper local level. The power to dominate refers to the ability of societal elites to make relations of power appear inevitable and natural (Fleming & Spicer, 2014). Unlike the action-based powers to coerce and manipulate, which are episodic in nature, this refers to long-term sustained efforts to persuade, through the endless repetition of ideology (Alvesson, 1987); the manufacturing of consent (Burawoy, 1979); and exerting pressure to conform to certain social institutions (Fligstein, 1987). A very important social institution that shapes power relations in Nepal is patronage politics. The ideology that underpins patronage politics holds that patrons and clients have moral obligations towards one another: patrons should use their connections and resources for the benefit of their clients – and in exchange, their clients should support the political and economic goals of their patrons. Non-conformity with these expectations can be punished as a moral transgression. As such, rural elites often perform their broker function as their 'duty' as patrons towards their 'clients'. Many Nepalis accept patronage politics as the status quo and have more confidence in patronage politics than in their weak formal institutions (as has also been observed elsewhere, e.g. De Waal, 2009).

The final form of power that contributes to local elites' control over access to information and knowledge sharing we will discuss in this paper is subjectification (Foucault, 1975). Subjectification is another example of systemic or 'invisible' power. It refers to how people's sense of self – and behavior towards others - is formed through the endless repetition of normative narratives around identity and behavior (i.e. "you should not touch Dalits, they are impure"). The establishment of 'formal categories of people' for legal or medical purposes feeds into this. At the hyper local level, these power relationships are manifested in numerous ways, such as inclusion and exclusion from power loci due caste or ethnic bias. Another example is the fact that property and land titles were generally registered in the name of husbands and sons: a practice that is generally regarded as 'normal' and part of the unquestioned status quo. (However, this custom made it hard for widows and the wives of migrant workers to claim compensation in the aftermath of the 2015 earthquakes). The power of subjectification also contributed to the fact that at community meetings, women would normally defer to men, considering it right that relief (and politics) be discussed by men. Table 1 below provides a summary of this analysis. It is important

[1] which is not to say that all Brahmans / Chhetris are rich, powerful and well-connected

to flag up that a power analysis is very context specific and that power relations that shape a particular space in one humanitarian setting will be different from those in another. The purpose of this analysis was to explore the links between connectivity, e-resilience and local power relations. We will now briefly discuss a civ tech initiative that specifically sought to address the problem 'offline' communities faced in terms of accessing information, broadcasting needs and holding local power holders to account.

Table 1 – A power analysis: the influence of patrons on decision making spaces at the local level

Power dimension	Levels	Spaces	Network position / social capital
Coercive (visible)	Local	Closed (behind the scenes decision making) Invited (at community meetings – power imbalance attendees)	Patrons (have large and diverse networks)
Agenda setting (hidden)	Local	Closed (behind the scenes decision making) Invited (at community meetings – power imbalance attendees)	Brokers (bridge position in network)
Hegemonic (invisible)	Local	All (systemic)	Patrons (client dependency = broker position cannot be challenged)
Subjectification	National	All (systemic)	Paternalism (broker position = how things should be)

Mobile Citizens Helpdesks

On the day after the first earthquake, the open data and accountability civ tech organizations Accountability Lab and Local Interventions Group launched an initiative called Mobile Citizens Helpdesks. During the initial relief and recovery phases, every month they sent volunteers with hand-held devices into the 14 worst affected districts, reaching out to communities at the hyper local level. In addition to surveying affected communities about their views on the effectiveness and fairness of the response, the Mobile Helpdesks volunteers also acted as information conduits, providing communities with answers to their specific questions, addressing their particular needs. They would, for example, help victims use the radio to reunite with their families, find out how get to hospitals for critical surgery, find tents to sleep in or find out how to get the damage to their homes assessed. Being well connected to government actors and (I)NGOs at the national level, they enabled a vertical flow of information, sharing the surveys upwards, with national level actors, and sharing the insights gained from their contacts at government bodies and (I)NGOs downwards. Mobile Citizens Helpdesks worked closely with national level actors during the relief and recovery phases of the humanitarian response. In the immediate aftermath of the earthquake, the initiative was, for example, supported by a 1234 hotline, manned by volunteers based at the Nepalese Home Ministry. Linking up with the commercial sector, the initiative was also supported by a SMS toll free platform managed by a private company (Sparrow SMS). Furthermore, in partnership with UN bodies and INGOs, the surveys fed into a joint Inter-Agency Common Feedback Project. As such, Mobile Citizens Helpdesks made an effort to integrate its data collection approach with the processes used by formal responders, thus ensuring that the information collected also addressed the needs of these organizations.

Humanitarian and government organizations generally recognize the potential of open crisis data civ tech platforms, but struggle to make effective use of such initiatives. They find it hard to fit this kind of information into their organizational routines given technical incompatibilities and the time pressure inherent in a disaster response (e.g. Hughes & Tapia, 2015). As such, the strategic choice the Helpdesks made to design compatible data collection formats and processes greatly contributed to the uptake of their work. This choice constitutes a calculated use of format or template power (Castells, 2013). Actors who determine the design of technical formats and organizational routines have the power to enable or block effective connections between their own organization and potential partners. However, whilst helpful in terms of uptake, there was also a downside to designing instruments, templates and routines fine-tuned to the specific interests of partner organizations and donors. This downside was that 'miscellaneous' information that affected communities shared that did not fit' the standard reporting formats (and was perceived as not particularly relevant to partners and donors) was not adequately captured.

Citizens Helpdesks also sought to establish itself as a key actor at local level. The civ tech initiative recruited two local people with established networks to key local stakeholders (including ties local government officials) as ‘frontline associates’ in each district. These associates lived locally and made sure that their phone details were known widely in the community, so as to ensure accessibility. Central to the work of the Helpdesks were its efforts to link up affected communities to key actors at all levels. They used the established Nepali tradition of ‘community meetings’ in order to create an ‘invited space’ (Gaventa, 2004) so as to connect citizens with village and district level actors. Being vertically integrated with ties to influential actors at all levels (including the national and global level) they sometimes managed to secure the attendance of Chief District Officers at these community meetings. This is relevant as these actors are at the heart of all formal government and NGO relief and recovery initiatives at district level. Being incredibly well connected, these influential nodes can use their large and diverse networks to facilitate vertical relief and recovery efforts.

As such, Citizens Helpdesks sought not only to provide community members with a platform where they could ‘voice’ their concerns – but also attempted to connect them with institutional actors who had the ‘teeth’ to take action on the basis of these concerns (Fox, 2016). Furthermore, they gave ‘eyes’ to stakeholders at all levels by inviting local journalists to these meetings (e.g. those working for local radio stations). Indeed, many of their frontline associates were professional journalists themselves. By facilitating the public recording and broadcasting of what was discussed at these meetings they aimed to put pressure on local power holders to act in accordance with their promises. Aware of the different power relations that shape community meetings, the Citizens Helpdesks made a conscious effort to ensure that the voices of those less confident were also heard. Women and disabled people often felt uncomfortable publicly expressing any views at these meetings. The volunteers from Citizen Helpdesks addressed this issue by collecting their views prior to the meeting and having someone else read them out.

Citizen Helpdesks thus created an invited space where civ tech volunteers sought to mediate power relations between participants. They made a real effort to ensure that the civ tech initiative was fully integrated along all levels: the local, the national and the glocal. Joint initiatives were set up with formal responders, which ensured that collected data was compatible and useful for these organizations. Perhaps most importantly, the Helpdesks stimulated vertical information flows in both directions. They sought to boost e-resilience by linking ‘offline’ communities up to wider information networks through focal points with handheld devices, but also by relying on traditional ICTs, such as radio and cell phones. Indeed, their volunteers acted as conduits for offline communities to online glocal spaces. By providing alternative ties to the wider world, the Helpdesks somewhat reduced local elites’ influence over information flows and provided rural communities with more options for leveraging the social capital in their geographically dispersed personal networks.

DISCUSSION AND CONCLUSION

Access to information and the sharing of knowledge have the potential to shape the effectiveness of all stages of disaster management, from prevention to recovery. As such, civ tech initiatives are (rightly) believed to have *the potential* to boost community e-resilience and make a humanitarian response more agile and adaptive to specific local conditions (e.g. Meier, 2015). At this point it is important to consider that historically most new technologies have been hailed as democratizing and liberating forces when they first came to market (Winner, 1980). Whilst these innovations - such as factories, cars and radios - clearly did (and do) hold the potential to empower communities, the actual impact of these technologies on people’s agency has varied greatly by social group and by social context over time. In all these examples, actors in positions of influence have been able to shape both the technologies and the socio-economic relations surrounding them – to tailor to their own needs. Indeed, artifacts and technologies have a distinct political dimension (ibid).

In their article on vulnerability assessments, Pronk et al. (2016) show how measurement instruments and evaluation procedures (i.e. assessments) designed to measure social vulnerability to tsunami risks in Portugal reflect the perceptions of vulnerability common among national-level government bureaucrats - and not those of local stakeholders. In our analysis of the instruments used by the Mobile Helpdesks in post-earthquake Nepal we identified the same pattern: the instruments were calibrated to collect information that national and global level partners and donors considered important and did not adequately capture the other ‘miscellaneous’ information affected communities shared. As such, these technologies were not ‘neutral’ but embodied the priorities and beliefs of those with power. If, in the case of Portugal, all national level bureaucrats boarded a spaceship to Mars and never engaged with tsunami vulnerability evaluations again, their priorities and beliefs would continue to influence the assessments as their views have become encoded in the instruments and processes that are central to how vulnerability is measured. Indeed, in this sense technologies have agency of their own, independent from their current users. The priorities and interests of those who influenced their design continue to shape the social settings that use them even when those 'designers' are long gone (Winner, 1980). When we look at the design of the ICT network infrastructures in Nepal, we note that urban areas are served by better more reliable structures, whereas rural areas depend on sparser, more vulnerable networks. This lay-out clearly reflects the interests of urbanites and is a product of the historic power imbalances between urban and rural Nepal. This pattern holds when we zoom in to the last mile in rural Nepal. As we have described above, in rural communities, elites had better and more reliable ties with wider information networks than less privileged groups. As such, the latter were more likely to become disconnected as a result of the impact of the earthquake.

Digital inequalities are a form of systemic invisible (hegemonic) power that plays an important role in shaping how civ tech initiatives influence e-resilience. Social media has the potential to greatly boost local response capacity because it enables the sharing of resilient behaviors through peer-to-peer learning – and caters for diverse and contextualized learning needs (as opposed to a top down 'one size fits all' approach to informing) (Dufty, 2012). Many civ tech initiatives aim at boosting e-resilience by fostering self-organization and learning at times of disaster by enabling community participation in a humanitarian response – and by making crisis relevant information publicly available through open data platforms. They create what Gaventa has termed 'claimed spaces' through which they aim to empower both communities and responders so as to make the response more agile and adaptive to local circumstances.

However, digitally underprivileged groups often struggle to participate in online spaces that have been created for the sharing of knowledge and coordination in times of disaster, especially when the disaster has taken them effectively 'offline'. Their lack of connectivity means that they are limited in the extent to which they can share information or organize collectively with geographically distant nodes in their network, such as their migrant husbands or sons. Due to their lack of e-resilience, they are often forced into a greater position of dependence on local elites, who – thanks to their influence and resources – are generally able to quickly reestablish their connections, if they got disconnected at all. As a result, control over the flow of information gets concentrated into the hands of local power holders. Whilst these men may have the best intentions for their communities, the fact that people have few alternative means of accessing information means that they are not able to hold these men to account. In this paper we have provided an example of how a civ tec could be strategically deployed so as to boost local accountability through e-resilience, using focal points, hand-held devices and 'traditional' ICTs to link up the last mile.

In summary, our power analysis of the social and material relations at the final leg of information networks shows how different forms of power shape community e-resilience. We have endeavored to show that civ tec initiatives have the potential to boost e-resilience at the last mile, provided they strategically and critically engage with the power relations that mark the settings where they operate and the context of their own design. Platforms that limit themselves to providing tools for civic 'side-efforts' may end up not being used by responders. Civ tec initiatives that believe themselves to be 'a-political' may inadvertently reinforce systemic inequalities. Our case study shows that it is possible for civ tecs to boost e-resilience through strategic vertical integration, linking 'offline' communities at the 'last mile' to district and national information networks. Our case study also shows the tension between ensuring uptake by humanitarian responders and capturing the priorities of affected citizens on the ground as the information provided may not be the information that is wanted. A power analysis such as the one presented in this paper could help civ tec initiatives critically reflect on their potential impact so as to make informed and strategic choices in terms of how they position themselves.

ACKNOWLEDGMENTS

The authors wish to thank the people at Accountability Lab, Local Interventions Group, Kathmandu Living Labs and all other respondents who generously shared their time with us towards realizing this study. We also wish to extend our gratitude to Marije Visscher, Julie Ferguson and the editors and the anonymous reviewers for their invaluable insights and comments. The research carried out for this paper is part of a project sponsored by the Netherlands Organization for Scientific Research (NWO), Division of Social Sciences, Smart Disaster Governance (Project 409-14-003):

http://www.nwo.nl/en/research-and-results/programmes/smart+governance/Enhancing+smart+disaster+governance

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Operational applications and perspectives

Business Intelligence Model for Disaster Management: A Case Study in Phuket, Thailand.

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ABSTRACT

This research presents the conceptual Business Intelligence (BI) model for disaster management. BI can provide agility capacity for decision making in dynamic environment among different agencies. This project designs and develop a data warehouse using multi-dimensional model for severity analysis of flood and landslide in risk area using case study from Department of disaster prevention and mitigation (DDMP), Phuket, Thailand. The concept of BI can be applied for extremely heterogeneous data structures and data platform environment to improve data quality and expose to better decision-making for disaster management. In the next stage of this project, we will integrate more data sources from other agencies for example GIS data from Phuket land-use planning and flooding prediction model database. The result of this study will help organization deploy BI more effectively.

Keywords

Business Intelligence; data warehousing; decision support system; conceptual model; disaster management.

INTRODUCTION

Disaster management is commonly described in four phases including preparedness, response, recovery, and mitigation (Public Safety Canada, 2011; Summary, 2013). Each phase has the different activities which require the data to support as the following:

Preparedness phase is aimed at preventing a disaster at first phase. In the event a disaster occurring, then it will try to control its effect through suitable response and recovery strategies (National Preparedness Guidelines, 2009). The activity of preparedness includes planning, organizing, training, equipping, evaluation and improvement activities (Kadam, 2012) which requires the related information (plans, resources, and organizations) (Flachberger and Gringinger, 2016).

Response phase occurs after the crisis event has occurred, the aim is to minimize losses, saving lives, damages, and alleviating suffering (Summary, 2013). The Information which is required for the response may contain resources, needs, damages, threats and collaborations (Flachberger and Gringinger, 2016). The related activities include search, rescue, and emergency relief.

Recovery phase wants to return the community's systems and the activities back to normal in long-term. This phase is not similar to the response phase in its concentrations; recovery efforts are concerned with issues and decisions (Public Safety Canada, 2011). The activities of recovery phase such as claims, grants, and repair of importance infrastructure. Besides, the information is required for reducing damage (Flachberger and Gringinger, 2016).

The mitigation phase: effort to manage and reduce the risk to life and property. The information is required for decision support such as hazard, risk, forecasting, and impact of disaster (Flachberger and Gringinger, 2016; Eckle et al., 2016)

For examples in figure 1, each phase of the disaster management has the distinctive principles and information for employments (Flachberger and Gringinger, 2016; Summary, 2013). This information has in the both related public and private agencies, which are responsible for disaster management such as Federal Emergency Management Agency (FEMA) and Non-Governmental Organization (NGO) (Summary, 2013). In addition, there are also relevant agencies in Thailand such as Meteorological Department of Thailand, Department of Water Resources, and Department of Disaster Prevention and Mitigation in Thailand. Including data from social network such as Facebook, Twitter, and Crowdsourcing (Alexander, 2013; Calderon et al., 2014).

Data is distributed in dissimilar data sources which are multiple formations and extremely heterogeneous data. Those data sets make a large volume and a variety of data that can be classified into three types: structured data, semi-structured data, and unstructured data (Goes, 2014). The problem of research is the combining information from various sources into the data warehouse for decision-making processes. Therefore, the challenge of research is the data integration from heterogeneous data sources and constructed data warehouse for the agility and collaboration of disaster management. The concept of data agility can also apply to data warehouse architecture in real time to quickly adjust disaster management.

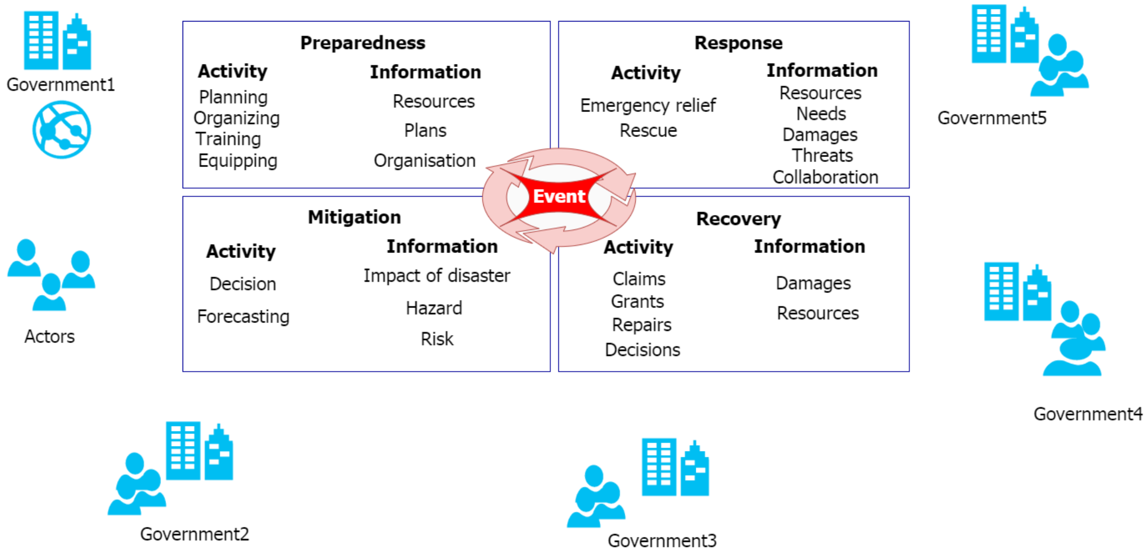

Figure 1. Information requirement for disaster management phases.

Nowadays, Information technology is commonly used to manage the problems of information (complexity, incompleteness, and variety). Examples of Information technology includes Management Information System (MIS), Customer relationship management (CRM), Enterprise Resource Planning (ERP), Big Data, Data mining and BI (Asghar et al., 2009). In addition to technologies are applied for knowledge: predictive modeling, association analysis, data segmentation and clustering, classification and regression analysis, and anomaly detection, in various applications (Chen and Storey, 2012). However most of the data processing, data warehouse, and data analytics are necessary workflows on BI platform which includes Microsoft, IBM, Oracle, and SAP (Sallam et al., 2011). BI can be integrated and improve data from many data sources for the complete process of decision making (Asghar et al., 2009; Chen and Storey, 2012). On the one hand, the risk is reduced and managed by Information technology (Iwasaki, 2013). The benefit of data warehouse is classified to four characteristics: subject-oriented, integrated, time-variant and nonvolatile. Subject-oriented, a data warehouse is used to analyze a specific subject area. For example, “Location” can be a specific subject. Integrated, a data warehouse can be integrated data from multiple data sources to a single database. Time-variant, Historical data is kept in the data warehouse which store many month or years of data for historical analysis. Non-volatile, historical data in a data warehouse is not modified (Chaudhuri, S. and Dayal, U., 1997).

This research presents the Business Intelligence model for disaster management. Next is methodology: data collection, data pre-processing, multi-dimensional model (fact tables and dimension table), BI analytics and data visualization. The final part is involved in the discussion, conclusion and work in the future. Researchers require to convert heterogeneous data into a single unified structure and stored for decision-making so researcher defined research questions. How to apply BI concept in disaster information management for decision making?

From questions, researchers studied and applied literature; disaster management, information technology management, and data integration, then we design the conceptual BI model for disaster management. Moreover, we selected Phuket province, Thailand in this case study because this province is the top business tourism and was involved in a natural disaster in 2005 (Henderson, 2007). Then research focused analysis as the following; 1) the severity of risk areas by floods and landslides. 2) The population and number of households were affected by the drought. The result can help employees for decision support in the case study.

RELATED WORK

Business Intelligence (BI) refers to the set of techniques and tools that help to transform a large amount of data from disparate sources into meaningful information to support decision-making and improve organizational performance. The most organizations use BI for analyzing data. BI has emerged as a major driving force for organizational performance (Ramakrishnan et al., 2012). Technically, the processes of BI include; Extract, Transformation, and Load (ETL) process, data warehouse, online analytical processing (OLAP), data mining, decision models and visualizations (Li Zeng et al.,2006; Olszak et al., 2003; Zhong et al., 2006). Most BI applications are used in Business and marketing while BI application of disaster management is scanty. The data warehouse is the core of business intelligence system which stores aggregated and historical data (Ballou and Pazer, 1985). It is loaded from many operational data sources i.e. MIS, CRM, ERP and other legacy systems (Ballou and Pazer, 1985; Li Zeng et al., 2006; Olszak et al., 2003). The transformed data into a data store that is subject-oriented, integrated, time-variant, and non-volatiles which are based on available information and enable people to decision making and trends in the future. A popular conceptual model that influences the front-end tools, database design, and the query engines for OLAP is the multidimensional view of data in the warehouse. The attributes of a dimension may be related to a hierarchy of relationships. The types of design data warehouse are star schema, snowflake schema, fact constellation schema. Star Schema structure is easier to query. These are the classic characteristics of the data warehouse (Bill Inmon, 1991). The data warehouse of the disaster was produced to response and recovery strategies (National Preparedness Guidelines, 2009).

Chen and Storey classified Business Intelligence & Analytics (BI&A) and provide a framework that identifies the evolution, applications, and emerging research fields of Business Intelligence & Analytics (BI&A). They represented the trend and growing of BI (Chen and Storey, 2012).

Gao et al. produce platform using crowdsourcing with crisis mapping that is called Ushahidi. In order to be more proficient and most effective in settling the emergency, the individuals from the reaction aggregate must subscribe to the brought together regulatory control of a data administration framework to guarantee information uprightness (Gao et al., 2011).

Nascimento et al. presented the conceptual architecture to handle the influx of information in Emergency Situations. Their Models were used to data implementation (from raw data sources to visual representations). Moreover, the solution help to identify interesting information on the dashboard (Nascimento et al., 2016).

Aulov et al. described AsonMaps which is the platform for collection, aggregation, visualization, and analysis. AsonMaps can geolocated information that be extracted from Instagram and Twitter. They focus a use-case scenario on Hurricane Sandy that devastated the East Coast of the United States in fall of 2012. They used NOAA's SLOSH model and P-Surge (probabilistic surge model) to produce a forecast for Hurricane Sandy (Aulov et al., 2014).

Sung et al. classified applications for the communication of disaster in Taiwan. It can be divided into 5 types include Educational apps, Follow-up apps, Disaster message boards, Alert notification, Location, sensor, and hazard maps. The mobile application has more important in disaster management so it occurs increasing data sources (Sung et al., 2011).

Calderon et al. studied to analyzing the sort of communications that happen through social media during a crisis, specifically a case study selected Hurricane Sandy. They claimed two areas of work; namely collective intelligence and group decision-making software. They need to increase effectiveness between people during the crisis, through technology and information. The collective intelligence of users, allowing them to make better individual and group decisions, so to help those afflicted by a disaster or those attempting to provide relief to help themselves. They were not so concerned information flows. They are interested in information as a necessity for collective decision-making (Calderon et al., 2014).

Olszak and Ziemba introduced the methodology of BI system, creation, and implementation. This research focus two major stages, 1) BI creation stage involves tools and technologies, which include ETL, data warehouse, OLAP, data mining and presentation tools. 2) BI consumption involves the fundamental changes in the enterprise. The researchers focused on the issue that organizations require some cultural background to go along with information system and information technology when building and implementing a BI system. This suggested a methodology of building and implementing BI system also need sound business practices set by the enterprise (Olszak and Ziemba, 2007).

Asghar et al. developed BI model that link dimensions of BI and processes, which is essential during the lifecycle of BI system development, for disaster management organization in Pakistan as a case study. The model is implemented and validated using Oracle BI tools and techniques. The data source has structured data from a part organization. They provide exploratory abilities on the data, and linkages among BI processes from the conceptual BI dimensions (Asghar et al., 2009).

CONCEPTUAL BI MODEL

Previous data in the BI system were stored as the database with relational structure (Asghar et al., 2009). However, at present, there are copious data: structure, semi-structured and unstructured, as identified in the definition of Big Data (Goes, 2014). Big Data is essential to disaster analysis and hence, the conceptual of BI and Big data is integrated and created as the model on disaster management. In this research, there will be defining conceptual of BI model for disaster management and figure 2 illustrates work process which can be divided into 9 phases including event, disaster phases, response, actor/center, data services, data storage, evaluation, BI analytics and BI virtualization as follows.

First phase: disaster can be categorized as 2 types including natural disasters such as drought, flood, wildfire, earthquake, landslide, and Tsunami or man-made disasters including transport accident, industrial accident, attack, or other accidents (Chandran, 2013; Kadam, 2012). It is necessary to manage disaster to handle with possible occurrences. However type of disaster is the first requirement, is applied with the second phase for defined and designed the data warehouse.

Second phase: Disaster phase uses the term "Disaster management" that has four phases including mitigation, preparation, response and recovery which are substantially different in terms of functions and processes. For example, mitigation is exercised for the longer term than another 3 phases. Preparation is to create the strategy to prevent disasters and to control functions of response and recovery. Response requires emergency service and local experts while recovery, the final phase, is targeted to recover the affected area. The information of disaster management flows from authorities and agencies to the public, from the public to authorities and from peer-to-peer (Goggins et al, 2010; Kadam, 2012; Public Safety Canada, 2011; Summary, 2013).

The third phase is about disaster actors and agencies such as U.S Federal Emergency Management Agency (FEMA), governments, hospitals, NGOs which are connected with the devices or system resulting in various and bountiful disaster data beneficial to analysis (Kim et al., 2014; Public Safety Canada, 2011).

Fourth phase: communication devices when disaster occur such as cloud, GPS, website, CCTV, sensor, satellite, employee and facsimile (Fax) which can transmit data externally and internally (Flachberger & Gringinger, 2016). Some data are managed as the database but some are dissipated without proper organization. Thus, it is necessary to create the data bank for different data storage (Kadam, 2012; Public Safety Canada., 2011).

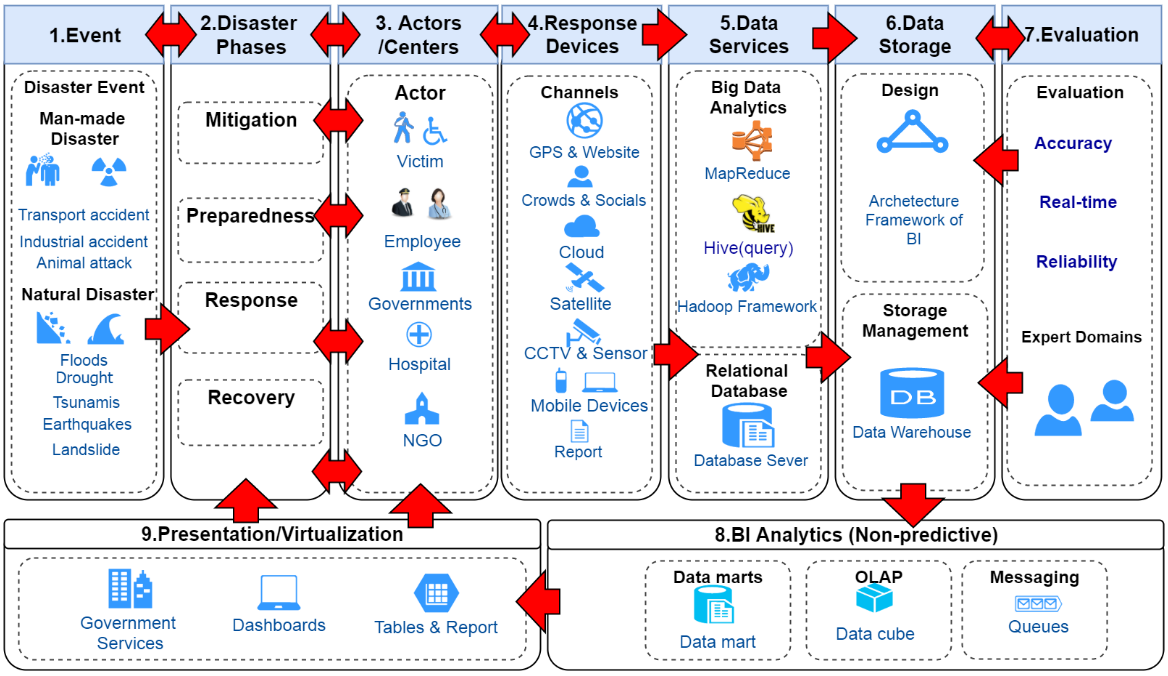

Figure 2. Conceptual Model of BI on disaster management

The fifth phase is the data collection from data services. They are divided two services follow as; 1) Big Data environment is defined by 4V'd: volume, velocity, variety, and veracity. Volume is big data's primary attribute, as terabytes or petabytes of it are generated by organization. Velocity is the speed data is generated and processed. Variety is the data come in all form: structured (traditional databases like SQL), semi-structured (with tags and markers), and unstructured (NO SQL). Kim et al., 2014) Big data is integrated by data-management systems for example, Hadoop which is open-source platform is the most widely applied technology for managing storage and access, overhead associated with large heterogeneous datasets, and high-speed parallel processing. That is called the distributed file system (HDFS) (Zikopoulos et al., 2012). HBase is used to store data and Hive is used for data summarization and ad hoc querying (Thusoo et al., 2010). 2) the relational database of the related agencies which is various structured data. Nevertheless, those data must be extracted and transformed by ETL process that is called data pre-processing, can be exercised to reduce irrelevant data and to improve data (Kim et al., 2014; Olszak et al., 2007; Shivtare and Shelar, 2015; Zhong et al., 2008).

Sixth phase: data warehouse is defined by a multidimensional conceptual model, store data from data pre-processing. Data warehouse is mostly implemented on standard or extended relational DBMSs, ROLAP and MOLAP servers. However, the data warehouse contains fact tables, dimension tables, and hierarchies into a multidimensional model in the form of star or snowflake schema (Asghar et al., 2009). Moreover, each fact table is defined measure and gain value. The designing data warehouse is significant and time-consuming; it is necessary to use the principles of the Business requirement to design the structure customized by the users and to improve data quality for effective analysis (Nascimento and Vivacqua, 2016; Olszak et al., 2007; Zhong et al., 2008).

Seventh phase: data warehouse evaluation is necessary for analysis. The factors of data warehouse evaluation can be divided 3 parts as the following: 1) structure of fact tables and dimension tables include accuracy, reliability and real-time. 2) The data quality of data sources. 3) Based on actual usage (Asher et al., 2009; Kim, 2014).

The eighth phase is BI analytics such as data marts, OLAP, and data searching which are the result effective and quick analysis required by the users with a multi-dimensional overview (Asghar et al., 2009). Data required for specific analysis will be stored as data marts that data dimension can be easily presented.

Ninth phase is the presentation from BI analytics so that the users can understand it quickly and easily. For data representation in cubes as a user interface. The data display can hierarchical operations; roll up and drill down at multiple levels of aggregations. Furthermore, the data visualization contains traditional graphics (point, bars, circular and histograms), table, report, tendency, complex forms (with the use of colors and geometric symbols), real images or mappings to the more representations by use of diagrams (trees, graphs and networks) (Nascimento et al., 2016). It is crucial to recognize the instruments of the users and presentation format. Examples of data visualization tools as Ushahidi (Ushahidi, 2013), VisTrails, the matplotlib library, Power BI, and Oracle dashboard. (Asghar et al., 2009; Chaudhuri and Dayal, 1997; Oliveira et al., 2014).

CASE STUDY

BI model in figure 2 is applied to a study area, Phuket province in Thailand. Phuket was selected as study area according to information about occurred natural disasters (floods, landslides, and droughts), provided by local authorities and previous interviews within the local expert domains. The scopes of research analyze as follows; 1) the severity in risk areas of floods and landslides. 2) The quantity of population and households were affected by the drought. Moreover, figure 3 represents research methodology. Researchers organized the research method as follows: data collection, data pre-processing, designed data warehouse (multidimensional model), BI analytics, and results.

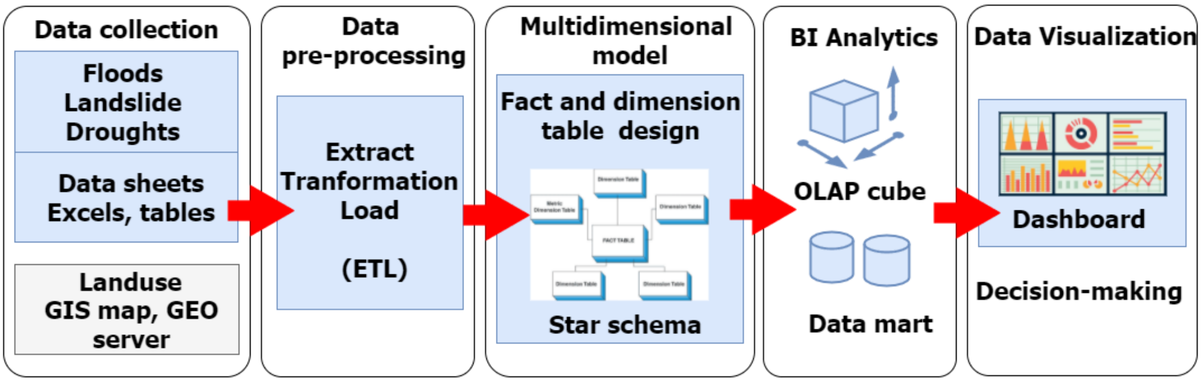

Figure 3. Research methodology

Data collection

In the case study, researchers collected secondary data from the Department of Disaster Prevention and Mitigation in Phuket center. The secondary data are extremely heterogeneous, both semantically and structurally, which contain information on several object types such as villages, sub districts, districts, population, households, time, geographical features, warning system, training, flood and landslide reports, and drought reports. These data were stored documents and table reports using the Thai language. Besides, we find and collect latitude and longitude of location points using Google Maps. Then, the data integration is created for disaster information management.

Data preprocessing

The researcher applied ETL process using SQL Server Integration Services (SSIS) on Microsoft Visual Studio 2015 and Windows SQL server 2014. SSIS is used to reduce noise data, convert data, set attributes and updates to multidimensional model (Shivtare and Shelar, 2015). For example, researchers need to convert the disaster subtype data from flat file to foreign key in dimension table (DIM_FLOODTYPE) using Dataflow which has many functions such as Lookup and Merge Join for data transformation. Then, converted data are loaded into the data warehouse.

Data warehouse

Data warehouse is the core of BI, must apply the information requirement for defined grain, measurement, user, dimension tables, fact tables, and BI analytics. Data warehouse or multidimensional data contains seven dimension tables (geographical features, Phuket location, time, flood types, water for agriculture, water for use, and water reserves). Each dimension table has two languages; Thai and English. Moreover, Data warehouse has two fact tables (flood and landslide table and drought table) and they were stored in data marts as the follow:

- Phuket location table (DIM_PHUKETLOCATION) has 10 attributes; 1) dimension key (KEY_LOCATION) 2) safety location (SURVIVAL_LOCATION) 3) district (AMPHOE) 4) sub district (TAMBON) 5) village number (MOO) 6) village (BAAN) 7) latitude 8) longitude 9) population (POPULATION) 10) number of households (HOUSEHOLD). For example of hierarchy such as district (Thalang) => sub district (Pa Khlok) => village number (no.2) => village (Baan Pa Khlok).
- Time table (DIM_YEAR) has three attributes; dimension key (KEY_YEAR) and year B.E. (YEAR_TH) 3) year A.D. (YEAR_EN).
- Type of floods table (DIM_FLOODTYPE) contains dimension key (KEY_FLOODTYPE) and type of floods (FLOOD_TYPENAME). For example of hierarchy such as Flood => Drainage Flood => No.1
- Geographical features table (DIM_TYPELOCATION) contains 2 parts: 1) dimension key (KEY_TYPELOCATION) and 2) geographical features.
- Water for consumption table (DIM_WATER_USE) contains dimension key (KEY_WATER_USE) and the sufficient quantity of water at the village level.
- Water for agriculture table (DIM_WATER_ AGRICULTURE) contains dimension key (KEY_WATER_ AGRICULTURE) and the sufficient quantity of water at the village level.

- FACT_DROUGHT is the fact table to compute the quantity of population and households which are affected by the drought. FACT_DROUGHT is designed and related 5 dimension tables; DIM_WATER_USE, DIM_WATER_AGRICULTURE, DIM_YEAR, and DIM_PHUKETLOCATION. The measure of this fact is the quantity of population and households in village level.
- FACT_FLOOD_LANDSLIDE is the fact table which is divided three parts, primary key, foreign key and the measure. The measure of this fact table is computed from the score severity in risk areas. The score of severity was classified according to table 1. Furthermore, the Department of Disaster Prevention and Mitigation also acknowledged and suggest the factors of calculated the score of severity in table 2.

FACT_FLOOD_LANDSLIDE is related to four dimension tables; DIM_PHUKETLOCATION, DIM_YEAR, DIM_TYPELOCATION, and DIM_FLOODTYPE. We map them on the logical multidimensional star schema that is called data warehouse shown in figure 4. Then, the data warehouse can be pre-computed to Online Analytical Processing (OLAP).

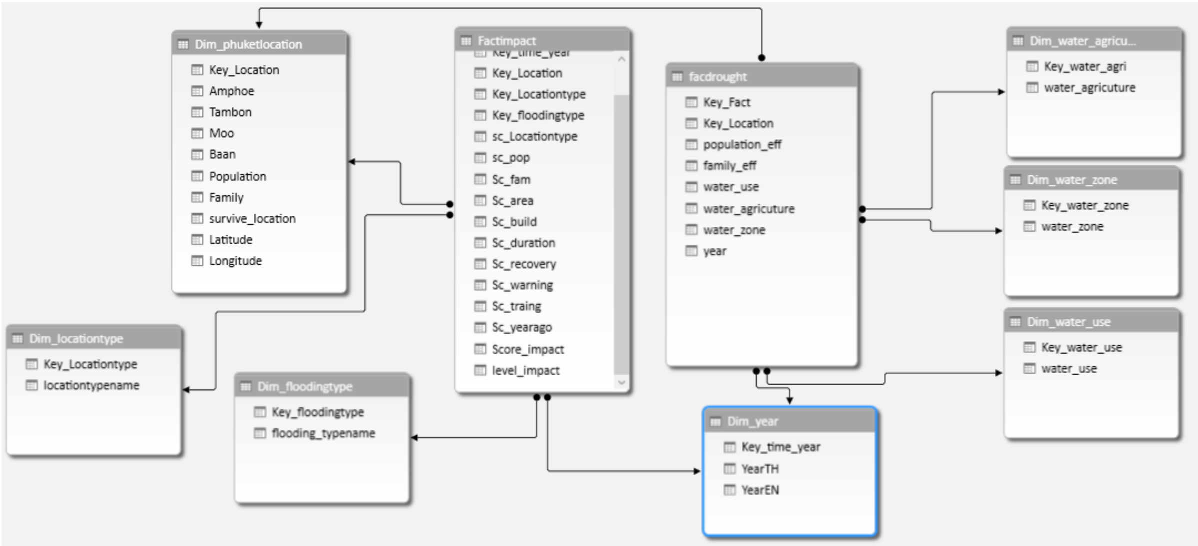

Figure 4. Multidimensional model

Table 1. Score of the severity in risk areas

Score range	Severity level
0 ≤ Score < 30	1 (Low)
30 ≤ Score < 60	2 (Medium)
Score ≥ 60	3 (High)

Table 2. The factor of severity in risk areas

No.	Factor
1	Geographical features
2	The damage that occurs as population, households, buildings and agricultural areas.
3	Duration the occurrence of the disaster.
4	Rescue tools
5	Warning system
6	Training staff
7	The number of occurrences in the past.

BI analytics and data visualization

Researchers analyze the data warehouse using OLAP engine. Researchers use Microsoft Power BI Desktop (Power BI) which is BI tool for BI analytics and BI visualization. We implement the multidimensional schema in logical level, import to Power BI. Moreover, we select the visual presentations (graph, table, and map) from user requirement. There are two factors for presentations; measure and filter. The measure of visual presentation is based on the value in the fact table. Moreover, the dimension tables can be used to filter or axis. The users can select common operations to include drill down, roll up, and pivot on the dashboard. In the case of study, we have classified two reports on dashboard; 1) the severity in risk areas of floods and landslides. 2) The quantity of population and households was affected by the drought.

For examples, figure 5 presents the first dashboard that shows an overview of severity in risk areas of floods and landslides in Phuket province. We analyze from the measure in fact table (FACT_FLOOD_LANDSLIDE), the score of severity and the severity level in each tuple of the multidimensional model. The information can be presented from shallow level to deep level, which depends on defined grain and hierarchy. Figure 6 shows the location of Thalang districts in Phuket, has five sub districts and twenty-seven risk villages. Furthermore, the results of two risk villages (Baan Ta Reua and Baan Nua Toon) are presented two big red points on Bing map. The score of Baan Ta Reua is 61 and Baan Nua Toon is 63. They have the high level of severity in risk areas of floods and landslides in 2015. The right table of the dashboard shows the severity score, the severity level, and the quantity of population and households in each risk villages. Besides, line chart shows the percentage of the geographical features and pie chart shows the percentage of flood types.

The second dashboard in figure 7, the quantity of population and households were affected by drought in Phuket. This dashboard contains the slicer, map, table, and bar graphs. The left map shows an impact of drought which consist of the total number of people and families in each village. They are taken as a measure in the fact table (FACT_DROUGHT). Then, the dashboard has 2 bar graphs, the sufficient quantity of water for agriculture and consumption. The results of bar graphs as follow: 1) the number people of sufficient water is more than the number people of non-sufficient water for agriculture 2) the number people of sufficient water is less than the number people of non-sufficient water for agriculture consumption. Moreover, the data display of dashboard can hierarchical operations; roll up and drill down at multiple levels of aggregations. Figure 8 shows Krasatti sub district of Thalang district, Phuket province has sixteen affected villages in 2015. Two villages (Baan Daan and Ban Phru Somphan) represent the big blue points on the map, are high impact by drought. These dashboards are easy to understand and they operate data display at agility. They can be applied to planning and preparation in the future.

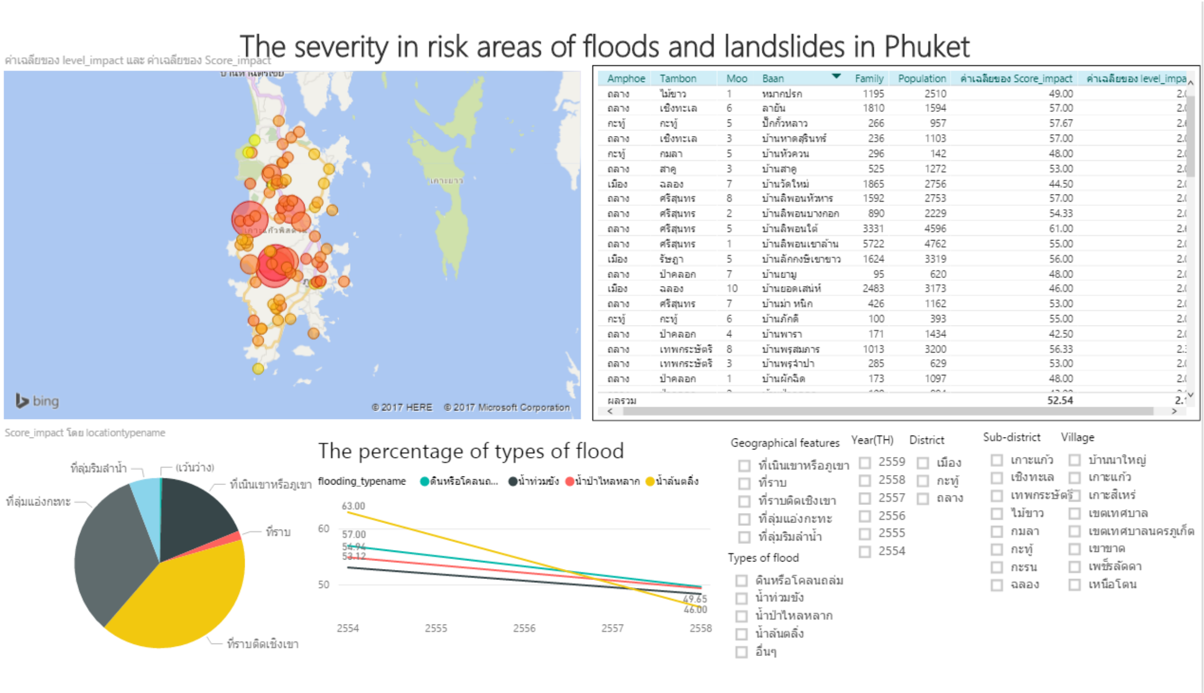

Figure 5. The overview dashboard of the severity in risk areas of floods and landslides in Phuket province.

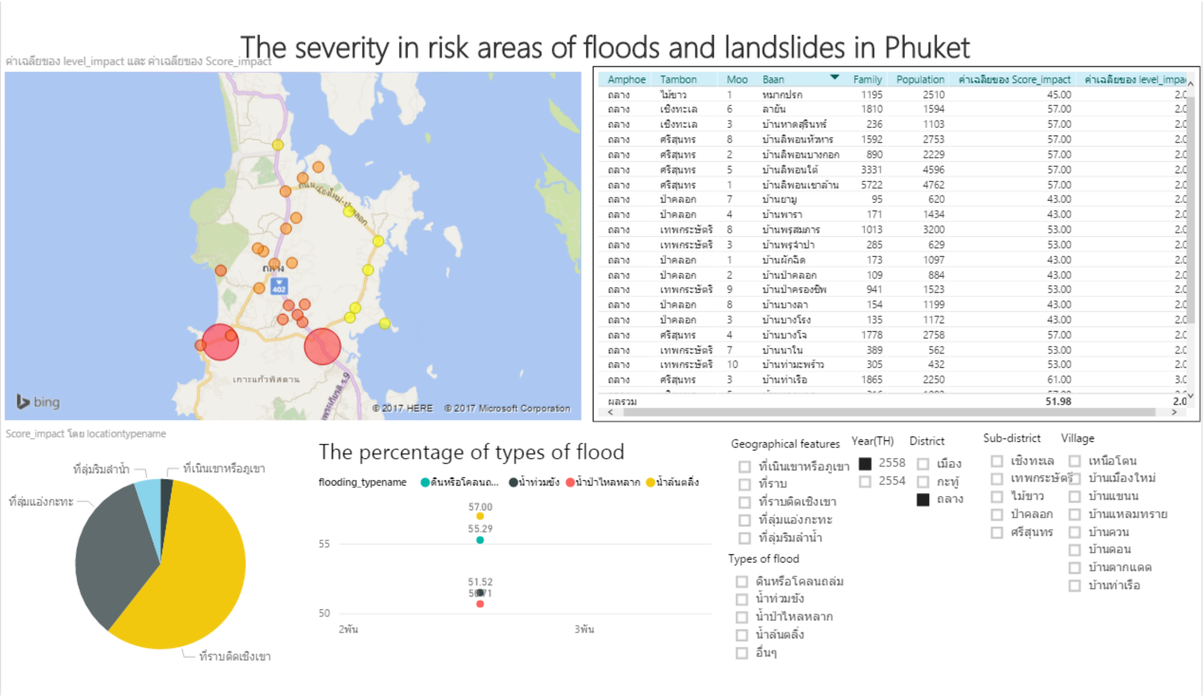

Figure 6. The dashboard of the severity in risk areas of floods and landslides in Thalang, Phuket province (in 2015).

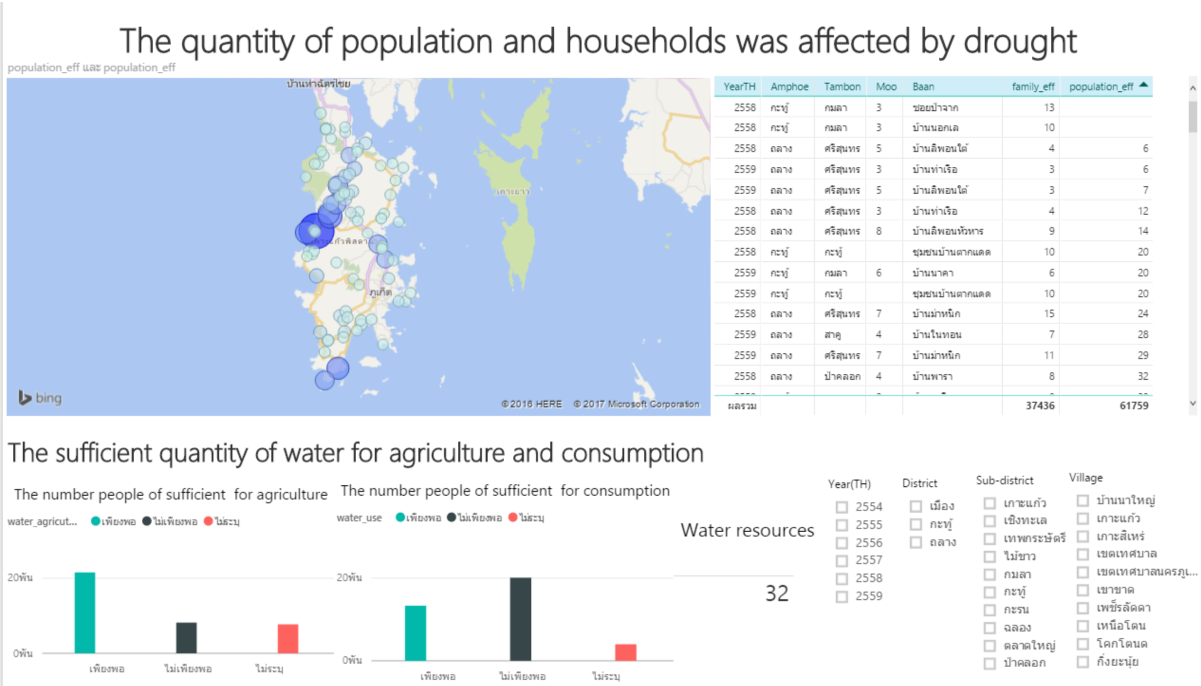

Figure7. The overview dashboard of the quantity of population and households was affected by the drought in Phuket.

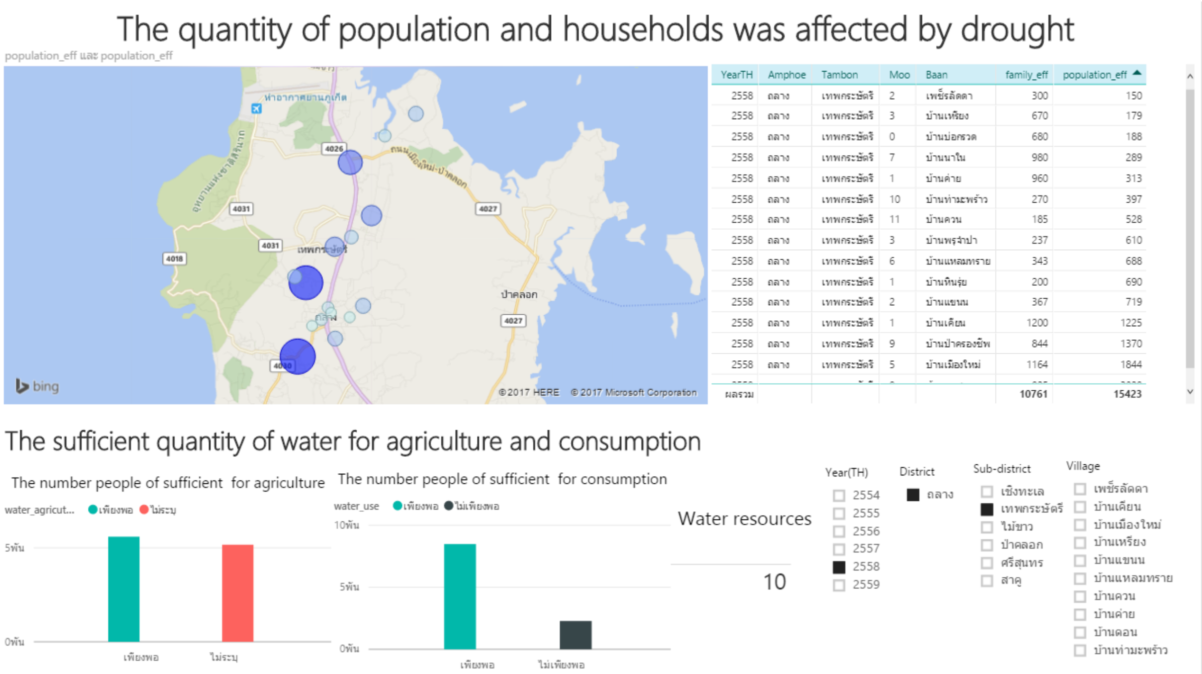

Figure8. The dashboard of the quantity of population and households was affected by the drought in Thep Krasatti, Thalang, and Phuket province (in 2015).

DISCUSSION

There are many BI contributions in decision-making for disaster management area:

Sharing information among disaster management agencies is the key success for decision making in each phase of disaster management life cycle. Using data integration techniques in BI can extract data from the variety of data resources such as databases, documents, media files, web services, satellites, scientific instruments, and web pages. Loading in Data warehouse, is used to store disaster information in specific subject area. User can select the specific subject, is based on multidimensional model. It contains the measurement in fact tables which improve effective analysis (the severity in risk areas). Moreover, data warehouse can analyze the historical disaster data to help the scenario forecast. Then, the raw data is not transformed in old databases. These are the features that are different from general database (Online transaction processing: OLTP). Data analysis using BI analytic (OLAP) can be represented in the multiple dimension of data. BI analytic can execute the multidimensional model from hierarchical operations; roll up and drill down at multiple levels. Filtering out irrelevant information and summarize information which are syntheses of all the relevant data can help for more situation understanding and decision making. Using interactive dashboard with the ability to filter, sort, group, drill down and visualize data also allow to easily delivering information and analytics understanding.

From the prior results, we collect some feedback from domain experts in DDMP Phuket. There are some issues in data quality and usability. Data quality; 1) data dimension design and the measurements in this system can be affectively used for strategic plan improvement in flood, landslide, and drought prevention. 2) The capability of roll up and drill drown in area dimension can help user deeply understand in the specific area. However, there is some suggestion in time dimension which can be improved to be more level of the hierarchy. Usability; because the project is in the first stage of development. Therefore, there are some limitations in data source acquisition and data integration. However, this pilot project will be extended to the next stage which can promise for disaster risk assessment and planning in the future.

CONCLUSION

Data Integration for disaster management is challenging because of the complexity in disaster management life cycle which involve with different data sources from different agencies. This research applies Business Intelligence (BI) model for disaster management area using the case study from Department of disaster prevention and mitigation (DDMP), Phuket, Thailand. Focusing on 1) the severity in risk areas of floods and landslides. 2) The quantity of population and households affected by the drought.

In summary, using BI technology in disaster management data integration can provide agility capacity for decision making in the dynamic environment among different agencies. In next phase of this research, GIS data from Phuket land-use planning and flooding prediction model database will be used for more insight integration analysis. The result of this study will help organization deploy BI more effectively to support their decision making during the disaster management operations.

ACKNOWLEDGMENTS

We thank to the Department of disaster prevention and mitigation (DDMP), Phuket, Thailand for their contribution and support in this project.

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IT infrastructure at the Rio de Janeiro City Operations Center – the case of 2016 Olympic and Paralympic Games

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ABSTRACT

Rio Operations Center (COR) was the agency of Rio de Janeiro Prefecture responsible for monitoring the Rio 2016 Olympic and Paralympic Games operations, due to its role in the integrated management of the city operations. This paper presents a case study considering a brief theoretical reference and data collected through direct observations, interviews, internal documents and access to the systems and software used by COR. The analysis of the COR IT infrastructure and monitoring teams' preparation for the Olympics revealed a successful development of new teams and conflict solving practice. Despite the use of different sources of information and the development of specific systems for the event, the COR preparation faced some restrictions in analytical functions, security and integration among systems. Nevertheless, regionalization for monitoring and inter-agency coordination, cross-agency instant messaging, and a team for active monitoring of social media emerged as new practices, representing opening venues for future research.

Keywords

Mega-Events, IT Infrastructure, City Operations Center, Olympics, Case Study.

INTRODUCTION

Rio de Janeiro City has a history of hosting mega-events, for example the 2007 Pan American Games, 2011 Military World Games, 2013 World Youth Day, 2014 FIFA World Cup, multiple editions of Rock in Rio, and the annual festivities of Carnival and New Year. However, the 2016 Olympic Games provided a unique opportunity to test the operational management of the city of Rio de Janeiro regarding speed and quality of response, flexibility, protocols, and integration among the different organs of the city administration.

The Olympics generated the greatest operational complexity, since in 16 consecutive days the equivalent of 41 world championships (modalities) were performed with approximately 10,900 athletes, 27,000 registered media professionals, 45,000 volunteers and 7.5 million tickets available (Rio de Janeiro City Prefecture, 2016). Slightly smaller in numbers, the Paralympics, with the equivalent of 23 championships (modalities), approximately 4,350 athletes, 10,000 registered media professionals, 25,000 volunteers and 1.8 million tickets available (Brazil, 2016) were also a great challenge, since the 12 days of competition took place in the period without additional holidays decreed by the Rio de Janeiro City Prefecture.

The Rio Operations Center (COR) was the leading agency in the operational management of the city during the Olympic Games. The agency was created in response to heavy rains that occurred in Rio de Janeiro in April 2010, to manage five risk dimensions: prevention, monitoring, mobilization capacity, communication, and constant learning (Rio de Janeiro City Prefecture, 2015). The COR is an important organization on the public services chain of Rio de Janeiro, since it houses representatives of more than 30 public, private (concessionaires) and press agencies, with tools and technologies for monitoring and controlling city resources, enabling a rapid emergency response.

The combination between risk management practices and supply chain integration (SCI) practices - including coordination and collaboration - are both associated with the improvement of operational performance of organizations (Kauppi et al. 2016). Such cooperation, however, is not self-evident or suddenly achieved in crisis management operations (Boin et al. 2010). Moreover, considering that only few Olympic Games and World Cups were hosted in developing countries, Molloy and Chetty (2015) note that a mega event as the 2016 Olympics can be considered an excellent opportunity to analyze the event legacy. Thus, the main goal of this work is to analyze both the COR IT infrastructure and the monitoring teams preparation for the integrated management of the city operations of Rio de Janeiro during the 2016 Olympic Games. The research method selected for this analysis is the case study, analyzing the data according to the pattern matching technique. First, the existent theoretical reference of IT infrastructure and monitoring teams in mega-events is presented, then, these findings are compared with data observed and collected of COR preparation. If the patterns match, the results reinforce the internal validity of the previous findings and the case study, whereas the differences observed in the real case operations may lead to the improvement of the theoretical reference to practitioners (Yin, 2013).

After this introduction, the methodology section explains the use and the choice of the case study and how were the analyses of the data collected through direct observation, interviews, and access to internal systems and COR documents throughout the preparation period for Rio 2016 Olympics. Then, the theoretical reference section presents the literature review of the IT infrastructure and monitoring teams in mega-events for City Operation Centers. The following section describes the COR planning and preparation regarding the IT infrastructure and monitoring teams, and their interaction in the information flow. Next, the data collected of the COR preparation is compared with the theoretical findings, revealing both the COR attention to previous findings in IT infrastructure and monitoring teams and the COR gaps in these subjects. Finally, the last section presents our main conclusions and perspectives of future studies for the data collected from COR during the Games.

METHODOLOGY

The case study methodology is selected for this research (Yin, 2013), once the realization of the Rio 2016 Olympic Games and the COR operation is a unique event, has many more variables than data points, with several sources, and there is a theoretical base to help planning. Regarding case study stages (i.e. plan, project, preparation, collecting the evidence, analyzing the evidence, and reporting), in the planning stage, the present research considers the limitation to observe only the COR internal operation, not covering any political, city's infrastructure, nor the Rio 2016 Committee decisions. Moreover, the present paper analyzes COR planning and preparation for the Olympic and the Paralympic games, not covering the results of their implementation on the city operations during the Games which will be left for a future work.

Planning and project design for the case study included a literature review of publications in the Scopus database, performed in August of 2016 in order to gather research addressing mega-events operations. Preparation secured authorization from COR chief officer for a six-researchers-team conducts evidence collection through direct observation of activities, the daily briefing meetings of the operational teams during the Games, interviews with key executives and operational staff of COR, and complete access to internal systems, documents, and IT infrastructure. Evidence collection corresponded for more than 29 days accompanying COR daily operations, amounting 639 hours of direct observation, 15 detailed interviews with key individuals, and 129 briefing meetings. Besides, a massive amount of data was collected in log files from some COR systems (such as social media files). Follow on work will deal with the analyses of all material.

THEORETICAL REFERENCE

Internal Management is one of the key areas regarding the practice of integrated management of operations. Using a public health perspective during mega-events, Enock and Jacobs (2008) and Meehan et al. (1998) note the importance of establishing a Command and Control Center and the formation of teams for monitoring and planning. They also discuss training and qualification of these teams - as well as Smith (2011), in a context of resilience analysis to identify the risks of the mega-event host. Parent et al. (2011) also stress the importance of ensuring team engagement and proper Human Resources Management.

In this sense, Kushnareva (2014) affirms that processes executed in city operations centers are knowledge intensive, complex, and require the support of intelligent systems for the execution of activities that depends on many different stakeholders. Parent et al. (2011) further discuss the importance of decision making structures that cover a certain degree of flexibility and formalization of strategic plans for group operations.

Regarding IT Infrastructure for city monitoring, Vargas and Bergonzelli (2015) indicate the use of cameras and video analysis for this purpose, and Huber et al. (2015) point out the importance of using remote equipment and data networks for communication. Perdikaris (2011) discusses the relevance of software that provides information in an integrated and georeferenced way. Del et al. (2012) and Huber et al. (2015) highlight the importance of risk management systems, and Cardoso (2013) points out the importance of a common programming language and software standardization. Kushnareva (2014) speaks about intelligent systems for to support user decision making in control centers. Kassens-Noor and Fukushige (2016) indicate that the Technology Operations Center (TOC) for the Tokyo 2020 Olympics need to improve the use of data connections and high-quality equipment.

Del et al. (2012), Monze (2012), Parent et al. (2011), and Smith (2011) stress the relevance of information sharing in mega-events operations. However, Monze (2012) additionally indicates the need to assess security levels and proper authorizations of certain information for the various agencies involved in the mega-events operation. Smith (2011) and Monze (2012) note the relevance of fast communication and information exchange, including the use of various resources such as video and audio.

Németh (2016) stresses the importance of clarity in information sharing to avoid conflicts among different members of agencies involved in mega-events operations. Patton and Flin (1999) also point out that conflict management in multi-agency management is a high source of stress for those responsible for coordinating mega-event operation groups. In this sense, Klauser (2015) further discusses the importance of negotiation and adaptation in the resolution of conflicts among those agencies.

As far as practices in media and social networks are concerned, Yang et al. (2012) indicate that the communication of information about locomotion, places of competition and others about the mega-event contribute to public satisfaction. Another important practice discussed by Amaral et al. (2014), Cornelissen (2012), Santos Junior and Santos (2013), Rosenthal and Cardoso (2015), Rowe (2012), and Ystanes (2015) is the proper communication management to deal with the response to social and political claims contrary to the mega-events.

RIO 2016 SUMMER OLYMPIC GAMES AND COR

COR Organization and Preparation for the Olympics

COR reports directly to the mayor is organized into a chief executive officer and four subareas: infrastructure director, technology director, resiliency administration, and operations sub-chief which embraces the monitoring team, denominated Operational Coordination of the City. To prepare COR for the Olympic operation without having to deal with COR's normal operations, a Planning Team was created in 2015. Part of this preparation included planning and preparation for other mega events, such as the 2015 Rock in Rio assembled in Barra region, where the future Olympic Park was constructed; the city's famous annual Carnival that happens in the streets of most neighborhoods; and 2015 Reveillon that gathers about two million people in Copacabana beach during New Year evening. This Planning group implemented other new teams in the COR operation, setting up and training human resources, and preparing operational and IT tools to ensure a broad, horizontal integration link between agencies involved in the city operation during the Olympics. During this phase of Olympics planning, three new teams have been organized: the Olympic Coordination; the Integrated Urban Mobility Coordination (CIMU); and the social media group (ROL16). These new teams were integrated into the existing Operational Coordination and performed the operations as follows:

- Operational Coordination of the City: a team composed of operators from traffic management, security, weather, energy and gas concessionaires, among other agencies of the Prefecture, including the press office. This group is responsible for the real-time, everyday monitoring of the city, acting directly in the solution of cases that alter the routine of the city (demands); activating and integrating the organizations involved in a given occurrence; and acting as a focal point of the city's operational activities mediated by the City Coordinator - which helps the resolution of the main demands, acting as a maestro of the situation room and leading the discussions of the operational briefings that happened three times per day;

- Olympic Coordination: team responsible for the integration and monitoring of the city's operations focusing on the Games. The Olympic Coordinator acts similarly to the Operational Coordinator but focused on Games-related issues, with operators divided in the four game clusters (Barra, Copacabana, Deodoro, and Maracanã, see Figure 1), plus a fifth one, called gray cluster, which covered activities scattered all over the city, such as the marathon and bicycle competitions, touristic points of interest, and dedicated Olympics lanes for athletes, referees and media movements. With briefings twice a day at the transition between shifts and sharing the situation room with the Operational Coordination (Figure 2), this team monitored the previous planned operational activities, and engaged agencies responsible for solving demands that arose during the event;
- Integrated Urban Mobility Coordination (CIMU): a team composed of representatives from all transport concessionaires, the municipal guard, public agencies that work with urban mobility (public and personal passenger transportation, traffic management), a municipal communications professional and CIMU Coordinators. During the Olympic Games, this team had three briefings a day, and executed three key tasks: monitoring the flows of viewers; responding with integrated actions to the occurrences or operational problems of transportation modes according to appropriate contingency plans; managing the information in the real-time message group, whether to inform operational teams and managers or citizens and Olympic spectators;
- ROL16: team created to boost the regular activity of monitoring social networks, which, during the Olympics, aimed to identify perceptions and demands from viewers in the competition venues and live sites, like Olympic Boulevards (places where population and visitors without tickets for the event watched the games), as well as potential issues coming from demonstrations. These social network advisors, ROL16 operators, were integrated in the Olympic coordination with one operator for each cluster;
- Planning Team: a team responsible for determining and organizing the main events, gathering information of the competitions and operational planning of other agencies of the City management involved in the Olympic operation, consolidating planned games activities, and inputting all this data into COR systems (mostly PRIMUS, detailed next). Moreover, this team was responsible for developing a organ, roster their functions and contact telephones - the Communication Plan (PLACOM) - to help operators and coordinators to solve demands from the Olympic operation. Another responsibility of this team was the creation of regionalized instant messaging groups to improve communication among the teams located inside the COR structure and operators in the field, with an average of 125 representatives per group, including the Mayor in some of them. During the Games, this team was responsible for managing the changes in daily planned activities for the Games; supporting other teams in monitoring activities during the Olympic Games; and delivering situational awareness of the main Olympic operational challenges in any given day and respective days ahead during the briefings, acting also as an integrator among different operational teams.

Figure 1. Rio de Janeiro cluster map
Source: Adapted from Rio de Janeiro City Hall (2017)

Team disposition was defined as illustrated in Figure 2 which contains the layout of the situation room, that in 2010 (when COR was inaugurated) had the largest video wall of the Latin America and room for about 70 operators. The new structure of the situation room located the new team on the right side, with one bench for each of the four competition clusters, another bench in the central for the grey team, and a last bench dedicated to the IT support team that helped all the operators and the Olympic and Operation Coordinators regarding IT issues. During the Olympics, CIMU was located in a physically separated room from the situation room that also had a smaller video wall and three rows of benches. The situation room also has a mezzanine for the media (television and radio broadcast networks).

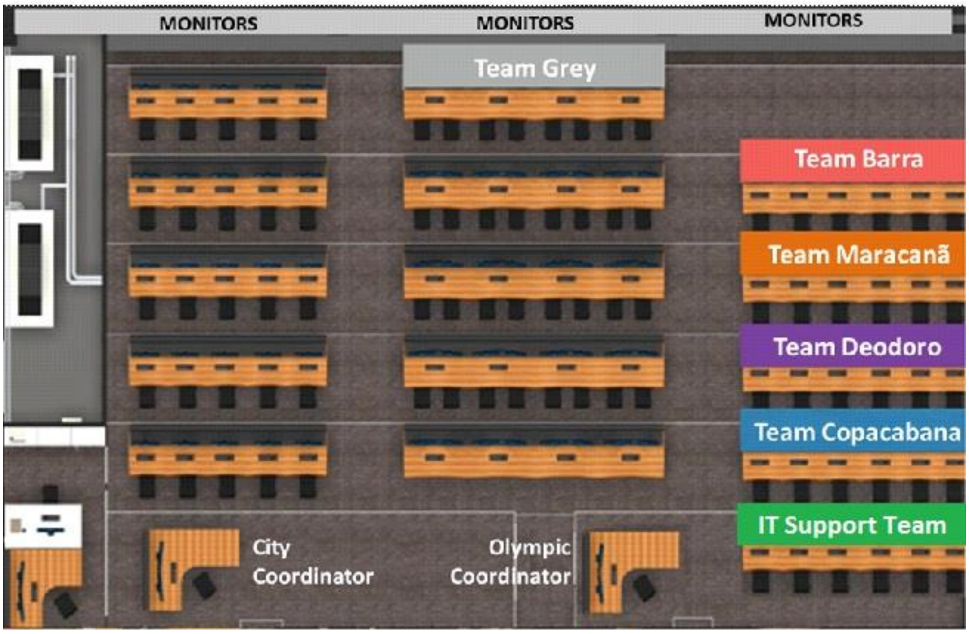

Figure 2. Layout of COR Situation Room during the Olympics

In the transition period for the Paralympics, the Planning team implemented the plan to reduce the number of operators from the Olympic Coordination, regrouping two regional clusters in a single bench. This change free up space in order to place CIMU inside the Situation Room. Thus, the Planning Team defined to join of the

Copacabana and Maracanã benches, likewise the Barra and Deodoro, releasing two benches dedicated to CIMU. Moreover, due to the physical proximity between the Olympic Coordination benches and the CIMU ones, both teams performed their briefings together.

Regarding the integration among the three teams, each coordinator in their briefing could ask the presence of the others coordinators. The Planning Team also had an important role in this integration, as explained, but the most important integrator tools were systems and software developed and adopted by COR.

IT Infrastructure for City Monitoring

As presented in the Theoretical Reference section, the operations management and IT Infrastructure regarding surveillance and city monitoring in mega-events, as the Olympics, are commonly addressed in the academic literature. However, the way these systems, software, new communication channels and social media interact with the daily operations routine, and stakeholders' relations, is not so usually described. COR is an integrator body in the Olympics operation, being responsible for the communication and resolution of problems that sometimes involve a significant number of responsible bodies and an even large number of possible affected ones. In this sense, the use of intelligent systems is a natural way to the center since its inherent necessity to generate, acquire and share information among the organs.

COR deployed an array of systems and applications, either developed by their IT staff or by partners, used in the Operational Coordination daily activities, such as GEOPORTAL, COMMANDO, MAESTRO, and S4C (detailed below). However, due to the inherent characteristics of the Olympics operation, using their experience during the 2014 World Cup in Rio de Janeiro and test events for the Olympic Games, the Planning Team verified the need to develop a system to register planned activities and demands that arise from actual operations during the event - which resulted in the development of PRIMUS and PALANTIR systems by COR IT staff. In addition, for instant communication among operators, Rio2016 standardized the TELEGRAM application, which also had the benefit to integrating with S4C, although there was also the minor use of WHATSAPP. Finally, due to the information needs related to transportation monitoring in the city, CIMU also used ZUP-RIO to access information related to CET-RIO (Rio's Traffic Engineering Company) operations. A summary of main systems employed by COR on the Olympics operation is presented below:

- GEOPORTAL: aggregator system developed by COR, starting in 2012 which replaced the RioMídia system used since the beginning of COR's operations. The system is a specialized Geographic Information System (GIS) for the Rio de Janeiro City and contains several layers of different information, some historical and others in real time, such as road travel speed, location of online disaster sirens, access to cameras of the municipality operated by the DIGIFORT application, real-time location of city security, and garbage collection vehicles. GEOPORTAL is also integrated with others systems from the City administration, such as COMANDO;
- S4C: aggregator system with GIS information from systems such as COMANDO, PRIMUS, TELEGRAM etc., allowing the monitoring with georeferenced layers, developed by the company Comtex, and made available for COR to use in 2016;
- MAESTRO: system to access several georeferenced cameras in the territory of the municipality provided by contract since 2015 under the responsibility of CET-RIO;
- COMANDO: system developed by COR in 2015 that records the main demands of the city indicating the responsible problem-solving organs, and displaying information in the Situation Room video wall to aid situational awareness among operators, coordinators, and media representatives;
- PRIMUS: system that also records city demands indicating the responsible bodies to solve them, but focused on the Olympic operation and used mostly by the Olympic Coordination operators to register incidents in the competition clusters. This system, developed by COR in 2016 specifically for the Olympics, was also essential to the operation monitoring because it also had recorded all planned activities for the competitions areas previously inputted by the Planning Team. Hence, it acted as a check list of detailed pre-assigned activities for the Olympics operations;
- PALANTIR: system developed by COR in 2016 that filters the most critical activities and demands of PRIMUS, displaying them in a differentiated way to highlight information by clusters of the main open demands in real time, main activities planned for the next few hours with the estimation of public arriving by hour in transport stations, venues and other key places of the operation;
- GEOFEEDIA: commercial software that allows to access georeferenced information of various social networks and to organize them in an interactive map, exhibiting most used words in defined areas or searching for the location in which certain words are used. The system is in use since 2015 through a

partnership between COR and the company Geist;

- TELEGRAM: free commercial application of instant messaging;
- WHATSAPP: free commercial application of instant messaging;
- ZUP-RIO – Zeladoria Urbana Participativa of Rio (Rio's Participatory urban welfare): system that registers requests/ complaints from operators in the field/on the streets. Developed in a partnership between SECONSERVA (Rio's agency responsible for the conservation of the city) and the company TIM, in use since 2016.

Others applications were connected to COR systems and add external information, such as Waze, Moovit, and Google Maps. In addition to these systems, there are two electronic documents filled in for the briefing meetings. The first one, the "Olympic briefing Agenda" was developed by the Planning Team to indicate the main activities of the next 12 hours of operations and in the briefings of all teams to aid the situational awareness among them. The second one, the "Operational briefing Agenda", with a summary of the main occurrences at the city in the last 8 hours of monitoring, was developed by the members of all the organizations and concessionaires in the Operational Coordination. Figure 3 presents the relationship among these systems and the two documents. Among these systems and documents, GEOFEEDIA and S4C are major information integrators.

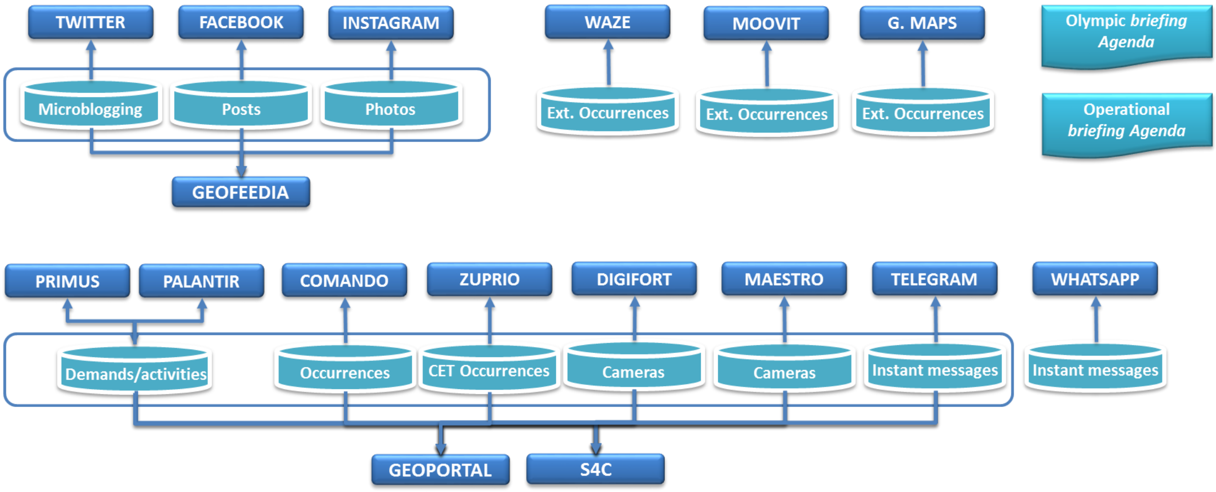

Figure 3. Systems and documents architecture used in monitoring

Aiming a global understand of the system interaction with the Olympic operations, Figures 4, 5, and 6 present the communication flow among the operators of different teams, according to the perspective of a team operator from each team involved in the games operations: the Olympic Coordination Operator, the ROL16 Operator, and the CIMU Operator. The delimited area in the figures presents the flows among the direct relationships between the operators and the documents, systems and the team coordinator, leaving for outside the delimited area the background relationship among the systems and other actors, such as the planning team member.

Figure 4 details the information flow of the Olympic Coordination Operator. The broad perspective of planned activities of each cluster come from the Olympic briefing agenda, the most important ones are presented in PALANTIR with details of public estimates and other useful information together with the main/critical open demand registered in PRIMUS. This last system is the channel to follow up the planned activities and register the demands. GEOPORTAL and S4C are also important information sources due to the integration of others systems as presented in Figure 3, the Olympic Coordination Operator looks for potential problems and occurrences that may disturb the Olympic operation and its planned activities. Finding a demand, the operator registers it on PRIMUS and inform the responsible to solve the problem that is already a member of the instant message group of the TELEGRAM. Depending on the complexity and impact of the problem/demand, the operator also discussed the case with the Olympic Coordinator to define a better solution.

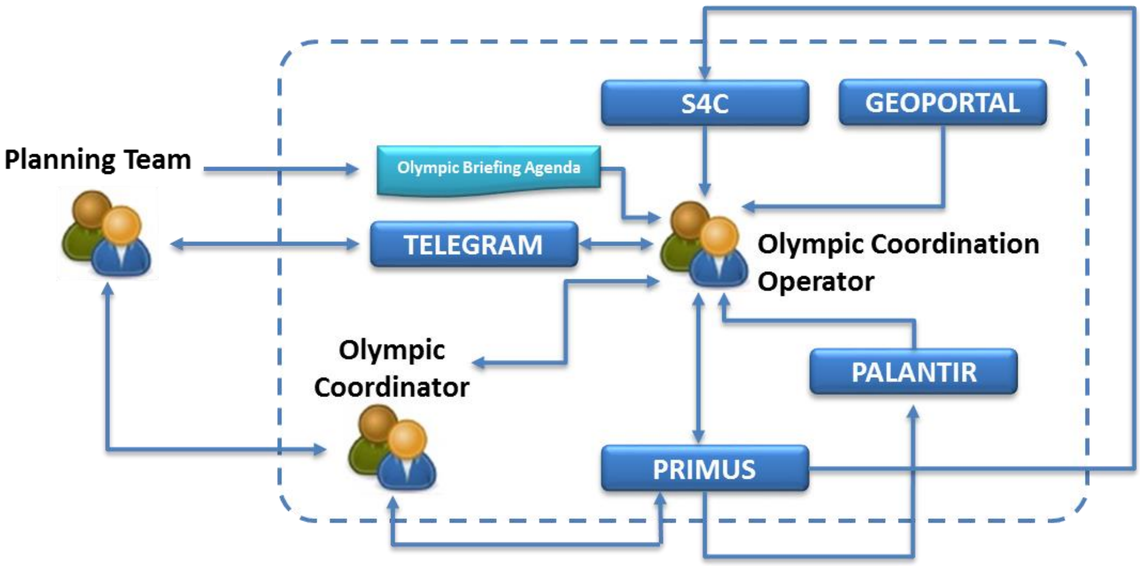

Figure 4. Communication flow of the Olympic Coordination Operator

Figure 5 presents the perspective of the ROL16 operator and how she/he would accomplish an efficient social network monitoring. Most of the information on its networks arrived via GEOFEEDIA, while the city and Olympic Operations information came from S4C, GEOPORTAL and the Olympic briefing agenda. ROL 16 Operators were not responsible for the problems solving or to monitor the implementation of planned activities, despites she/he should always consult the main activities from each cluster in PRIMUS to check the reactions on the social networks to support the monitoring of the Olympic Coordination Operator. The ROL 16 operator also provided such additional information for each demand through the TELEGRAM groups or to the Olympic Coordinator.

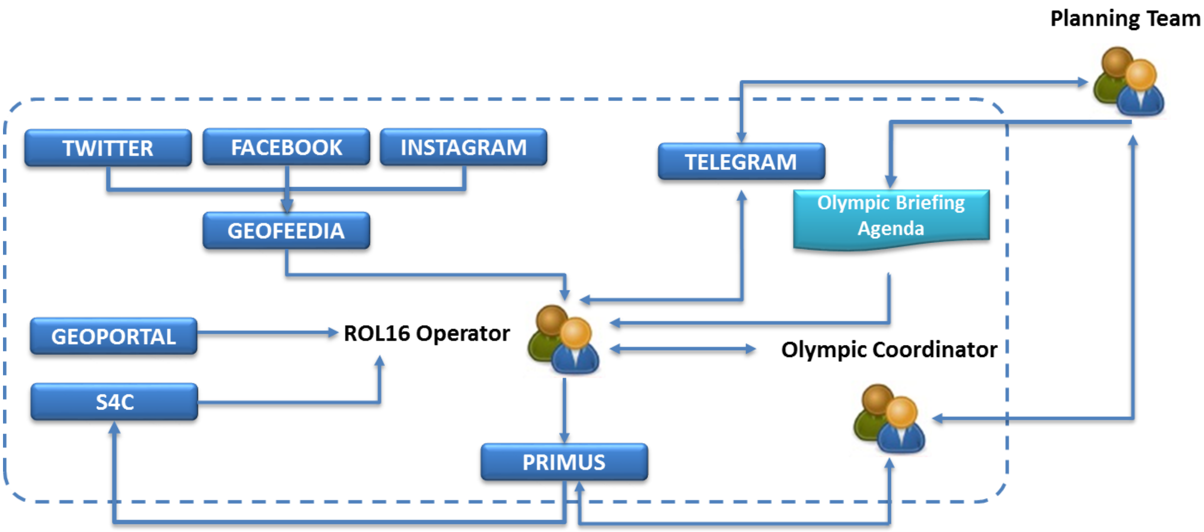

Figure 5. Communication flow of the ROL16 Operator

Each cluster bench in the COR Situational Room would always have two Olympic Coordination Operators along the Olympics and one operator along the Paralympics, likewise one ROL16 operator. Despite not being presented in the figures for simplification, there was also a direct exchange of information among the operators from both teams located in the same benches.

Finally, Figure 6 presents the CIMU Operator perspective. These operators, that represented the transport modals or related bodies of the city, needed a lot of information about the game operations for the monitoring of the planned activities and for solving any problem in the transport modals, including the implementation of contingency plans. In this sense, they gathered information about the Olympic Operation through the Olympic briefing agenda, PRIMUS and GIS integrators: S4C and GEOPORTAL. Besides, most of the CIMU Operators had access to systems from their modals and direct communication with the operations center of their modals. Therefore, if any problem was found, they could communicate the CIMU Coordinator to notify other transport modals, send a message to the TELEGRAM groups, register the demand on PRIMUS and report the transport modal operations center she/he represents, or update the situation on the system.

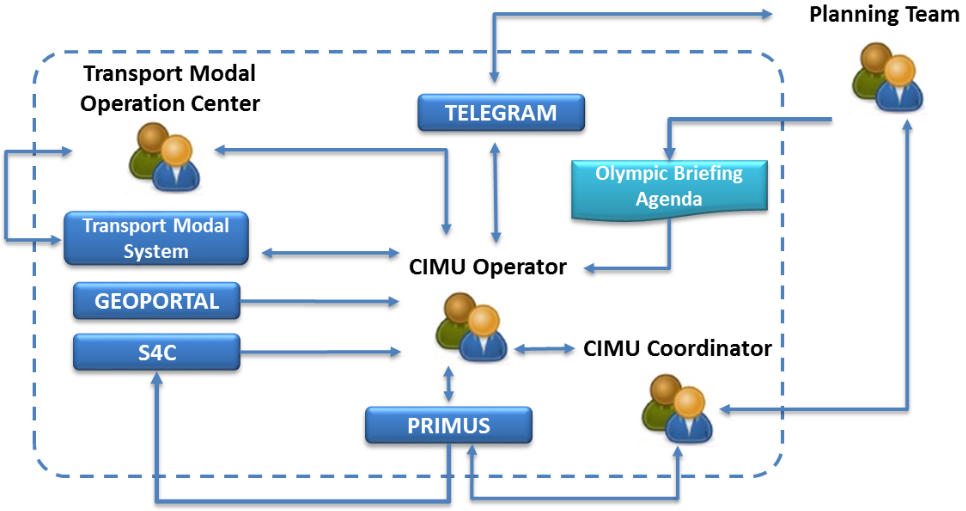

Figure 6. Communication flow of the CIMU Operator

ANALISYS OF THE IT AND THE MONITORING TEAM FOR THE GAMES

The theoretical reference of operations management in mega-events indicates the importance of multiple teams for planning and monitoring operations (Enock and Jacobs, 2008; Meehan et al., 1998) and such practice was observed in the COR preparation with the development of a Planning Team and others three monitoring teams. Regarding the training and qualification of these teams to acquire a more resilient perspective to anticipating operational risks (Smith, 2011), the Planning Team developed instructive videos for the team operators and training sections at COR facilities focusing on the IT infrastructure and the use of all systems starting in 2015. The importance of good human resources management and engagement, analyzed by Parent et al. (2011), was clear to the Olympic Coordinators, who motivated the operators with teamwork and Olympic spirit speeches since the early simulations and training sections. There were no morale issues during the games, with the strongest commitment from all involved in COR operations. The coordination responsibility in the conflict resolution (Klauser, 2015; Németh, 2016; Patton and Flin, 1999) was also observed by the COR leadership, who focused on leveling information rather than in the command level of the members involved in the decision making of the City and Olympic operations.

Among these practices, the main strength in the COR preparation was the development of a segregated Planning Team which did not participate in the daily routine of city operations long before the Olympics, and with executive coordinators coming with years of previous experience of COR management. In this period, that team had enough time to study and truly understand the challenge of the mega-event and, with the knowledge they already had of the center daily life, conceive not only new teams, systems, processes and routines, but also the preparation phase as whole, with simulations, human resources development, test events and involvement of all the departments and partners in the common goal of delivering the event. All of this preparation demanded a considerable amount of time and responsibility that implies this work team to be out of the daily routine and their normal roles in the institution.

Besides human resources, having systems with fast, well displayed and different sources of information is fundamental for a city operation center (Monze, 2012; Smith, 2011) due to their work nature with intensive knowledge processes, as explained by Kushnareva (2014). In this sense, the COR IT infrastructure is composed of several different sources and types of information, as described in the previous Section. The use of cameras and video analysis (Vargas and Bergonzelli, 2015) was observed in MAESTRO and DIGIFORT applications. The use of remote equipment, system and data network for communication (Huber et al., 2015) is correspondent to the use of ZUP-RIO that allows street agents to register and communicate demands, likewise the groups of instant messages in TELEGRAM that embraced municipality command and control chains, which were regionalized following the competition clusters. The system PRIMUS was the main software for the operations management because it gathered all the planned activities, decomposed into a series of very simple tasks to be monitored by different teams. The information from PRIMUS is used to feed a second system, the PALANTIR, which aimed to provide a situational awareness of the games sections due to its ability to present demands requiring response, besides the completed, delayed and coming activities during the entire event. For this reason, the PALANTIR can be considered a risk management system and the relevance on the use of such system is discussed by Del et al. (2012). However, PRIMUS and PALANTIR can still improve their performance management, reports, and advanced methods to support operator's decisions to anticipate possible consequences and risks by analyzing not only past experiences during mega events, but also past experience of the daily operations (Del et al., 2012; Kushnareva, 2014).

Concerning the information security, most of COR developed systems have none information sharing barriers after the login and password access, and thus, revealing opportunities for improvement in the security level of information, as suggested by Monze (2012). The use of a common programming language (Cardoso, 2013) was not fully observed in COR systems, but was softened with the use of GEOPORTAL and S4C, which are also GIS integrators that are pointed by Perdikaris (2011) as an important resource in the IT infrastructure. Having the GISs is very important for the regionalized monitoring implemented in the COR during the Games. However, it is worth notice that COR should have only one integrator system able to connect all the others systems, including the particular systems used by each agency with operators at COR. This integration among the systems was particularly pointed by the COR technology director as a subject of constant discussion since the beginning of COR operations in 2011.

Another relevant COR preparation action was the actively monitoring of social networks along the event for two main reasons. First, the ROL16 team was developed for monitoring the social media to identify possible demands or any kind of feedback that might help the monitoring of the Olympic Coordination operators. Second, the ROL 16 team was also responsible for monitoring the social media to acquire a better understanding and to support the operational response to popular social and political claims (e.g. verifying the demonstration path to support the best traffic rearrangement), even in demonstrations against these mega-events, which is described as a recurrent phenomenon in mega-events by Amaral et al. (2014), Cornelissen (2012), Santos Junior and Santos (2013), Rosenthal and Cardoso (2015), Rowe (2012) and Ystanes (2015). Nevertheless, through specialized professionals in social communication, COR's social networks pages aimed to enhance their regular work in sharing a wide range of information about weather, traffic, closed streets, public transport and mobility, and others, which contributed to public satisfaction, as indicated by Yang et al. (2012). Despite the discussion of demonstrations during mega-events in the theoretical reference, the development of such particular monitoring team represents an important innovation.

Lastly, the regionalization for monitoring a mega-event and the use of instant messaging are subjects that still needs to be deepened. During the preparation for the Olympics, the Rio 2016 committee presented to COR the main competition clusters and the COR decided to adopted them for the event monitoring and communications through instant messaging applications. This sort of regionalization was discussed by the Planning Team in order to define which public services should follow the new regionalization. Considering the size and the complex level of a mega-event, the regionalized monitoring of the city can be relevant, as considered in the case of Rio 2016 Olympic Games. Furthermore, the formalization of cross-agency groups of instant messaging also represents a relevant COR preparation action that is not discussed yet in the theoretical reference of operations management in mega-events. As analyzed by Kassens-Noor and Fukushige (2016), Tokyo intends to catalyze groundbreaking technological advancements for the city and Japan in the 2020 Olympic Games, which will also lead to a higher improvement in IT infrastructure for city monitoring by then, and the decisions presented in this paper represents subjects that can be considered in mega-events.

CONCLUSION

This work analyzed how the IT infrastructure and monitoring teams in COR were planned in the preparation for the 2016 Olympic and Paralympic Games. The analysis covered not only the software and the teams, but also their interaction in the information flow. From this integration perspective, the use of aggregator systems, social network analysis, instant messaging applications and the development of a Planning Team are identified as important characteristics for these operations.

Regarding the indications of IT infrastructure and monitoring team described in the literature on integrated management of city operations in mega-events, the present analysis concluded that COR fairly complied to them: the implementation of multiple trained and motivated monitoring teams; structure focused on to avoid team conflict; use of different information sources, cameras and video analysis, remote equipment system, and data network for communication; risk management system; and the monitoring of social networks and communication to the population also through social networks. However, there are opportunities to improve the systems intelligence to support the decision making of operators, also in the information sharing and security.

Further studies of COR operations during the period from August 5 to 21, 2016 (Olympics) and from September 7 to 18, 2016 (Paralympics) are planned for a future paper. All data collected from this period is still being processed in order to analyze the COR performance considering a broad perspective of integrated management of the city operations. Thus, implementation problems, how they were identified and solved, and good practices will be presented opportunely. Nevertheless, themes for future research on IT infrastructure and monitoring teams' preparation for mega-events can be suggested. Firstly, the analysis of all different types of systems and software/applications used in the monitoring could lead to develop a framework of a system integrator for mega-events. Secondly, the analysis of different city regionalization and definition of parameters for developing cross-agency instant messaging groups for communication and on site problems solving during mega-events could be addressed. Finally, other issue is the organizational challenges of mixing together representatives from so many different public organs from all government levels (prefecture, state, and federal), private concessionaries, and the event management (in this case, the Olympic committee).

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Logistics and Supply-Chain

Integrated Logistics and Transport Planning in Disaster Relief Operations

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ABSTRACT

Decision making in the area of humanitarian logistics and supply chain management often suffers because of the interrelations between planning horizons, tasks, and crisis management lifecycle phases. In this paper, we present a method, an exemplary prototypical implementation and its evaluation within a relief organization. Based on a structured literature analysis (a review of existing information systems as well as a consideration of ongoing research projects), basic requirements for an integrated logistics and transport planning approach were derived. Together with end-user involvement, these results were used to design and prototype a concept of an appropriate information system, which was applied and evaluated in a tabletop exercise. The generated results are promising in terms of having a positive impact on the logistics effectiveness. In combination with the identified limitations, our results promise to have an impact on future ISCRAM research.

Keywords

Humanitarian Logistics, Logistics Planning, Transport Planning, Use Case, Simulation, Routing

INTRODUCTION

Natural disasters affect significantly human kind. In the last years, Europe was troubled by several natural disasters (e.g. extreme flooding in June 2013 in Central Europe), which become more frequent and cause more damage (Bevere et al., 2013). The emerging nature of disasters has a deep impact on the requirements for humanitarian operations.

Being the main driver for the effectiveness and efficiency, the humanitarian logistics preparedness level of all involved actors, from non-governmental organizations (NGOs), over governmental organizations up to commercial providers, plays an important role for the responsiveness to major disasters. Procurement activities can sum up to 60 % of the total sum spend by humanitarian organizations and backlogs can lead even to break downs of operations. Another success factor of humanitarian operations is the ability to source goods from pre-positioned inventories. It is not only the most important time advantage that can be utilized here, but – as pre-positioning networks examples like the UNHCR show – well planned inventories offer a range of response coordination and cost benefits. As the practices of DG ECHO show, the importance of transportation support is considered as a crucial function of humanitarian operations. The transportation system is of outstanding importance not only for the mobility and the supply of the population, but also for professional responders who depend on functioning and reliable transportation infrastructures to reach the corresponding action places, to ensure evacuation and to provide the affected population as well as the emergency forces with goods and services.

Agility is a key attribute for logistics and transport planning. Information Systems can improve the preparedness and the responsiveness of humanitarian operations in Crisis Management by contributing to more agile responder coordination. As preconditions, information systems must have the abilities 1) to diagnose the divergence between the actual and the expected situation (detection) and 2) to adapt the current strategy coherent with the diagnostics (adaption). Moreover, it is vital that both tasks have to be performed fast enough and in a pertinent and accurate way to ensure a timely and effective reaction to the situation (reactivity and effectiveness).

The aim of the paper is to explore, how the combination of information systems from different phases of the crisis management cycle, functions and planning horizons can lead to a more agile crisis response and management. Therefore, the DLR and the WWU initiated a cooperation for the exploration of joined logistics and traffic management information systems within the EU FP7 project DRIVER (2014)*. The systems provide relevant information for crisis managers to cope with challenges of the logistics and transport chain during the preparation, respectively response phase in the crisis management cycle.

Within the paper, we first provide the results of a structured literature review and give then an extensive overview on available information systems for the planning (preparation) and response phase as well as on related work, concerning integrated logistics planning and transportation management systems. The goal is, to carve out the potential of integrating such systems, including identifying chances and risks, as well as to depict requirements and framework conditions for the implementation. In the second part of the paper, we present a concept of how such a connected system could look like. The theoretical consideration is complemented by a prototypical implementation and its evaluation of operating experience collected during a tabletop exercise performed with the Federal Agency for Technical Relief (THW).

RELATED WORK

Research in crisis management and humanitarian logistics has increased over the years, especially since the tsunami catastrophe in Southeast Asia in 2004. A growing part of this research is dedicated to the usage of information and communication technology in the field (Altay and Green, 2006). Humanitarian organizations more and more recognize the fact that also humanitarian supply chains can profit from and should be supported by supply chain management systems. In the year 2004, the International Committee of the Red Cross (ICRC) was the first organization starting to implement an IT-system comprehensively supporting them in tasks connected to the material flow in the supply chain. Nonetheless, only every fourth organization uses such a system while the others rely on spreadsheets or even pencil and paper (Blecken, 2010).

To get an overview of the current research on decision support systems in the context of disaster relief logistics, a structured literature search has been conducted. Three requirements, which a source needs to fulfill to be counted as relevant, have been defined:

1. It has to describe a tool, model or idea, which aims at supporting decision makers, i.e. provide decision support in some way.
2. The decisions to be made, resp. the problem dealt with, should specifically be within the scope of logistics or supply chain management. Sources dealing with general crisis management problems will not be considered relevant.
3. Finally, the environment in which these decisions need to be made should exhibit features of a crisis or disaster situation.

Accordingly, the following search term has been defined:

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"decision support" AND (crisis OR disaster OR emergency OR "relief operation" OR
humanitarian) AND (logistics OR "supply chain")
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Since all sources only presenting a model, which can be applied as a mean of decision support, or suggesting ways to enhance sense making in a crisis situation should be included in the literature review, two further search terms have been built by replacing “decision support” with “decision model” as well as “sense making”. The resulting three search terms have been applied to three literature databases: EBSCOhost, ScienceDirect and Scopus. The search has been limited to tiles, keywords and abstracts. Apart from this, no further restrictions (e.g. specific years of publication) have been selected. After a manual review of the results’ abstracts, relevant sources have been identified, which were used to provide an overview on how the topic of decision support in crisis logistics is treated in research.

Decision support systems developed and described in research mostly deal with problems from the preparedness and response phase. The most prominent problems handled are the facility location problem (e.g. Charles et al., 2016; Degener et al., 2013) and the delivery scheduling problem (e.g. Ben Othmann et al., 2014; Kuo et al., 2015). Very little research has been done on systems supporting decisions in the mitigation and recovery phases. An exception are Fallucchi et al. (2016) and Lorca et al. (2016), who deal with debris-related problems. Moreover, the results of the literature search show that decision support systems developed for logistics in crisis management in research are usually addressing one specific problem and therefore one management level and one crisis phase. Although it has already been recognized that decisions at different management levels or cycle phases are dependent on the ones taken at other levels resp. in other phases (e.g. Irohara et al., 2013; Kelle et al., 2014), only a very limited number of sources suggest decision support systems or models producing integrated recommendations across the crisis management cycle (Ransikarbun and Mason, 2016). Exceptions to this observation are for example, the stochastic programming model by Garrido et al. (2015), which aims at optimizing the inventory level of prepositioned relief items and the flow of those items after a flood crisis and consequently integrates decision problems from the preparedness and response phase.

Regarding the methods which are applied to provide support to decision makers, the by far most used one is mathematical optimization, including goal programming, stochastic programming etc. Especially when specifically considering sources which propose or even implement a system – in contrast to describing a model or framework – the minority applies techniques from other fields and an even smaller fraction of them use simulation. While most of those sources use simulation (e.g. D'Uffizi et al., 2015; Fikar et al., 2016b), there are others which combine simulation with optimization (Ben Othmann et al., 2017; Fikar et al., 2016a). Problems treated in these sources are all connected to the response phase and mostly deal with delivering relief items to people in need or more general with the status of the road network, i.e. with the question which effect sudden damages of single elements will have on the whole network. Fikar et al. (2016a) also investigate a collaboration between private and relief organizations.

Overall it can be observed, that decision support systems proposed in literature typically apply optimization techniques to solve a specific and restricted problem. Even though there are exceptions, still most sources follow this pattern. The usage of exact solution procedures deprives the possibility to include decision maker's experience and observations into the decision-making process. Moreover, optimization models are often not sufficient to depict the high complexity and uncertainty of a crisis situation. Especially the formulation of an adequate objective function is difficult because in a crisis different factors which are hard to express quantitatively, such as the life or suffering of people, play a major role in decision making. Simulation might be a technique to overcome the shortcomings of solely applying optimization (Ben Othmann et al., 2017; D'Uffizi et al., 2015). As a mean for supporting decision-making, simulation has already been widely researched in the context of commercial logistics (compare e.g. Terzi and Cavalieri, 2004). Reasons for utilizing simulations as a decision support tool are e.g. that a simulation model facilitates understanding of the real system and its behavior, provides a basis for discussion about it and is able to show previously hidden relationships and interdependencies. Moreover, the main advantage is the possibility to perform "what-if" analyses and be able to estimate a decision's effects before actually implementing it (Semini and Fauske, 2006). Nonetheless, for simulated solution proposals to be relevant, planning tools need to incorporate information from operative tools, which often provide exact solutions. Such a combination of simulation and exact solution techniques or operative tools can lead to the capability of adequately handling the complexity of a crisis situation (Fikar et al., 2016a).

Apart from decision support systems proposed in literature, there are also research projects, existing products and experiments dealing with the topic of decision support in disaster relief logistics. In the context of such projects, various tools are developed and suggested to serve as a mean of decision support for crisis logistics managers. The following table gives an overview about the tools obtained through an internet search and its intended crisis management lifecycle. Many tools for crisis management and decision support exist but with different levels of maturity. Due to a limited accessibility and varying available information, a rather general overview of the identified tools is provided. The tools identified in the search vary in terms of scope, purpose and degree of actual deployment. Further, it has to be noted that the list does not claim to be exhaustive, but it is meant to provide a first overview of the current landscape on logistics management and transportation tools.

Tool	Short description	Preparation phase	Response phase	Recovery phase
ELITE	web-based 'living document' for post-crisis lessons learning	X		
CRISMA	simulation-based decision support system	X		
FORTRESS	incident evolution tool that will assist in forecasting potential cascading effects	X		
CRIMSON	generic platform to train crisis managers and field crews	X		
SECTOR	secure European common information space (CIS)	X	X	
KOKOS	IT tools to involve the active participation of the general public for self-help activities		X	
Disaster LAN	Web-based task, mission and resource management system (only in the U.S.)		X	
SAHANA	Web-based collaboration tool for disaster response coordination between governments, NGOs etc.	X	X	
Fusionpoint	a web-based collaboration tool between emergency operation centers		X	
EmerGeo (EmerGeo Maping)	Common Operating Picture helping government and industry to mitigate, prepare for, respond to and recover	X	X	X
RIB / LUPP	tool for decision-making and follow-up of emergency response operations		X	
Ushahidi	Map-based web application to crowdsource data from people on the ground to aid relief efforts		X	X
SensePlace2	map-based web application that integrates multiple text sources (Tweets, News, Bloqs etc.)		X	X

Table 1. Overview of decision support tools for crisis management (Boin and Schaap, 2010; Chan, 2013; CRISMA, 2015; ELITE, 2014; FORTRESS, 2014; KOKOS, 2015; Morrow and Bachoura, 2013; SECTOR, 2014)

In the project CRIMSON a system was developed that offers an effective and generic platform combining simulation and virtual reality technologies for inter-organizational preparation, rehearsal and management of crisis situations, in order to train crisis managers and field crews. It allows the analysis and the evaluation of complex incidents, their impact on the population and contingency scenarios (Boin and Schaap, 2010).

Projects such as KOKOS (KOKOS, 2015) invent methods, technical concepts and IT tools to involve the active participation of the general public for self-help activities and communities integrated in processes of authorities. To enable the interoperability between first responders and police authorities during crisis situations or disasters, the project SECTOR (SECTOR, 2014) aims at establishing a secure European common information space (CIS). The CIS should give continuous and shared access to all necessary data and information, besides the use of collaboration process models to support coordination and cooperation between the organisations.

Another information management tool for the response phase is Disaster LAN (https://www.buffalocomputergraphics.com/dlan/emergencymanager). This web-based task, mission and resource management system for use in emergency operation provides tracking and reporting tools, emergency communication tools and visual situational awareness tools (e.g. Monitor and respond to Twitter and social media feeds, displays traffic cameras and video feeds, displays current weather, forecasts, warnings, and animated radars, includes user-to-user and system-to-system messaging…) to guarantee efficient team work. It is accessible for desktop and mobile devices. The tool seems to have a wide acceptance but appears to be only US-based and therefore not useful for European crisis managers (Boin and Schaap, 2010).

Besides, the Foundation SAHANA (https://sahanafoundation.org/) provides free and open source disaster management software. The offered information management solutions shall enable practitioners to better prepare and respond to disasters. It is a web based collaboration tool that addresses the common coordination problems during a disaster that help solve concrete problems (e.g. finding missing people, managing aid, managing volunteers, tracking camps) and ensures efficiencies in disaster response coordination between several participants (governments, aid organizations, the civil society (NGOs). The SAHANA Eden software offers a flexible, modular platform rapidly deploying information management systems separated to five categories (emergency, health, logistics, population and collaboration) with sub-categories for disaster management and humanitarian use cases. Except that the system is web-based and vulnerable if connection is not available, the system seems to be an appropriate tool for coordination during humanitarian aid operations and it addresses the problems of a common coordination during disaster (Boin and Schaap, 2010).

EmerGeo Solutions (http://www.emergeo.com/) offers a worldwide emergency and crisis management software and services that include two integrated products: Fusionpoint and EmerGeo Maping to use for planning, training and response. It is a subsidiary of Sai Infosystems Ltd. and the product is already used in market. Fusionpoint is a web-based software application that supports communication, collaboration and coordination within and between emergency operation centers (EOCs) and the field. EmerGeo provides a Common Operating Picture (mCOP™) technology, based on open standards, reliable world-class risk management technology and professional services that are proven effective in helping government and industry to mitigate, prepare for, respond to and recover from emergencies, natural disasters, acts of terrorism, and planned events (Morrow ad Bachoura, 2013).

Swedish Decision Support System RIB is a system for prevention and emergency management. It includes the computer system LUPP which is a tool for decision-making and follow-up of emergency response operations. Since LUPP is a partial system within the support system, it implies the necessity for exchange of data between different systems (Boin and Schaap, 2010).

Use of social media for crisis management: Ushahidi (https://www.ushahidi.com) and SensePlace2 (https://www.geovista.psu.edu/SensePlace2/): During the Haiti Earthquake (2010), the downloadable software tool Ushahidi was first deployed. It enables people to submit eyewitness reports during a disaster that can then be displayed onto a map in order to crowdsource data from people on the ground to aid relief efforts. Responders can use the data to improve their situational awareness and make informed decisions. SensePlace 2 is another map-based web application that integrates multiple text sources (news, RSS, blog posts) that can then be translated onto a map to allow emergency responders to easily filter through by place or time e.g. to analyse changing issues and perspectives (Chan, 2013).

Despite the existence of the manifold tools, one major challenge regarding humanitarian supply chain management systems is the fact that there is no tool being able to support all processes and tasks of logistics and transport planning while fulfilling general requirements such as easy setup, good usability and low costs. Aspects such as the analysis of the current logistics and traffic situation or an assessment of the infrastructure are not considered by any of the projects (Detzer et al., 2016). Tools developed specifically for humanitarian supply chains indeed mostly cover operational tasks leading to practitioners underestimating the tactical dimension when making decisions. Consequently, the combined usage of several tools seems to be the best option. But such a combination has to be well-considered as risks regarding data integration etc. are always arising when using different systems (Blecken, 2010).

CONCENPTUALIZATION OF AN INTEGRETAD LOGISTICS AND TRANSPORT PLANNING APPROACH

Dealing with the consequences of a crisis requires various tasks and activities in a humanitarian supply chain. Blecken (2010) has developed a reference task model to describe those and to point out how and where information systems can support crisis manager professionals in a disaster situation. The reference task model distinguishes between a strategic, tactical and operational planning horizon as well as functions assessment, procurement, warehousing and transport. This braking down in distinct management levels and functional dimensions results in twelve different areas each encompassing various tasks and in two additional activities - reporting and operations support.

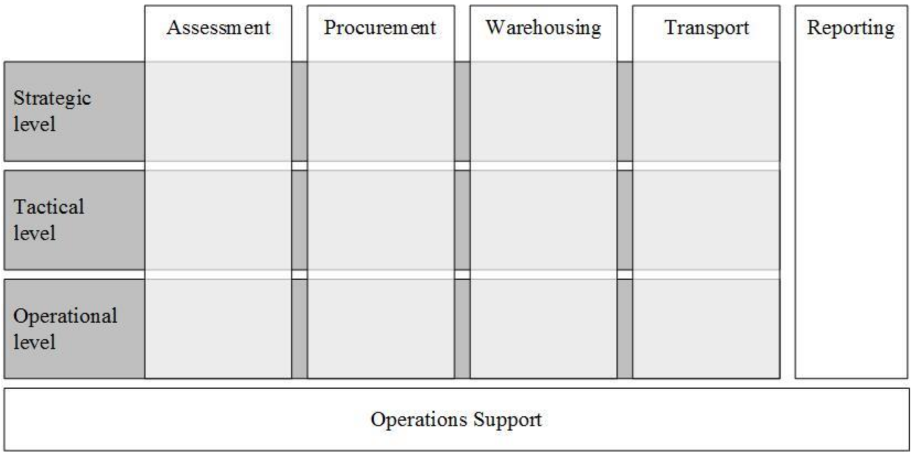

Figure 1. Reference task model framework (cf. Blecken, 2010)

Information systems can be used as a means of support for most of these tasks in several ways and this may have a beneficial effect on enhancing humanitarian aid. In fact, the four components of agility – detection, adaption, reactivity and effectiveness – define the way, how an information system can improve the execution of the tasks described above (Bénaben, 2017).

- Detection: Regarding all functional dimensions, i.e. assessment, procurement, warehousing and transport, monitoring capabilities of an information system can provide decision makers with relevant data about the current situation, i.e. stock levels or condition of the road network. In this way, the task to recognize and to keep the overview of deviations from expectations can be simplified.
- Adaption: Information systems can be applied to estimate the consequences of a certain strategy or decision without actually implementing the strategy or decision, e.g. by using simulation tools. This allows decision makers to select from a pool of suitable solutions and therefore enables to make decisions on more than experience.
- Reactivity: Information systems can accelerate the process of detecting deviations from the expected situation and reacting accordingly by providing timely and valuable information and presenting this information in a simple and comprehensible way.
- Effectiveness: Measuring the effectiveness of implemented strategies and decisions can be enhanced by information systems that for example collect and evaluate data about all performed crisis activities. Overall, an assessment of an operation's success is easier when it is based on a comprehensive data basis.

Available information system tools limit their scope in at least one dimension of the reference task model framework (see Figure 1). While often several functionalities are covered, the planning horizon is typically only considered on one level (namely strategic, tactical or operational). The majority of the provided tools concentrate on the operational level and only a few tools address the strategic or tactical level. This leads to the fact that decision makers in crisis situations usually underestimate tactical and strategic decision making and focus more on operational actions. One disadvantage of such isolated tools is that they cannot benefit from results or insights gained by other tools although decisions on different levels are dependent on each other. For example, the set of possible solutions for an operational decision is restricted based on the decisions made on strategic and tactical level. Such dependencies can be controlled, if information systems would be integrated on different levels. Thus, each tool can benefit from the information and results of all embedded tools.

Especially for logistics planning and transport management, a merging of various tools would enable an improved planning of resources' prepositioning and operating of transport orders. Thereby, possible transport routes as well as future traffic infrastructure conditions can be considered when deciding where to preposition resources (e.g. food, tents, medicine…). Moreover, locations of available relief items and demands for aid material can be considered into route planning. To unite tools of resource and route planning, it is essential to exchange various relevant information that the other tool can benefit from. The logistics planning tool needs to share information about warehouse locations, their inventory level of relief items, available vehicles and human resources as well as location of emerging demand. If the transportation tool is capable of processing the received information, it will be able to adapt suggested transport routes with regard to the given information in order to respond to the depicted situation.

The transport management tool in turn needs to provide information about the road network's condition, expected travel times and most appropriate transport routes to the logistics planning tool. By combining such information into e.g. simulation systems, the logistics planning tool becomes capable of suggesting better decision alternatives.

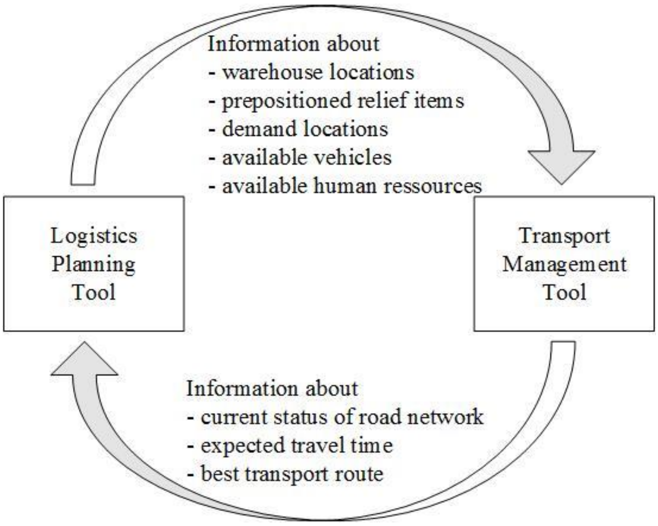

Figure 2. Information exchange between logistics planning and transport management tools

In order to be able to foster the possible benefits, different conditions must be met. Moreover, a technical integration of tools poses various risks, which need to be considered. For this, solutions to circumvent these challenges have to be developed.

Technical risks and requirements

From a technical perspective, the aspect of data integrations needs to be treated carefully. Only when integrating the different tools' data cautiously these can be interpreted and applied correctly. To ensure coherent data integration and valuable information exchange, consistent interfaces need to be programmed as well as suitable data processing functionalities have to be provided. In general, good data quality is important to enhance user acceptance.

Structural risks and requirements

Logistics planning and transport management tools operate on different planning horizon levels. Consequently, the different management levels need to be respected to avoid an uncoordinated and insufficient interaction between the tools. Moreover, risks of incorrectly shared information flows or overstimulation of information, e.g. by processing irrelevant information, need to be compensated when integrating tools of different management level. The overall aim is to consider the different levels and adapt the information flow to avoid useless information.

Socio-economic risks and requirements

From a socio-economic perspective the user acceptance is a high risk. If the integrated tools are not accepted by the user or do not address their actual needs, they will not achieve its objective and will not be capable of offering any benefits. To prevent this risk, an easy and efficient handling of the integrated tools has to be ensured.

Overall, a merging of a logistics planning and a transport management tool can be capable of closing the identified gap in decision support regarding logistics and transport related issues. At the same time, it has to be taken into account that such an integration comprises many risks and various requirements need to be considered when implementing it. Overall, an integration of a logistics planning and a transportation tool can be capable of closing the identified gap in decision support but such an integration offers many risks and various requirements need to be considered when actually implementing it.

PROTOTYPICAL IMPLEMENTATION

Based on the requirements identified above we have designed an integrated solution which can be applied for tactical as well as operational decision support within disaster relief operations covering logistics management and transport planning tasks. Until now, the integration is limited to the four specific tools mentioned below, but further integrations were considered during the design phase. Since the simulation-based logistics planning tool supports various import and export functions using Open Database Connectivity (ODBC) other related information systems (like warehouse management or enterprise resource planning systems) can be connected. The integrated tool aims at supporting practitioners to have an overview on its structures, capabilities, capacities and processes as well as to experiment with it during the preparedness and response phases. The integrated tool can be applied by different stakeholders covering disaster relief organizations, crisis management authorities as well as local and regional communities. However, the main target audience are relief organizations because the tool allows an exact depiction of organization-specific setups (e.g. physical networks or definition of standard operational procedures). The potential end users of the tool are the logistics and transportation responsibilities from tactical and operational levels (like project programmer, heads of operations or warehouse managers). By considering (global) assessment technologies, logistics planning methods as well transport management tools, decision makers are supported in terms of data-based comparisons of alternative decisions, i.e. the integrated tool is not aiming to tell practitioners what the optimal solution is, but it will demonstrate most probable consequences of individual solutions made based on the experiences of the decision makers.

In the following paragraph, we first describe which technologies were integrated in the overall solution and how. In the second part, we describe one particular experiment within the DRIVER (2014) project executed with the Federal Agency for Technical Relief (THW). Within the experiment, we have modeled the THW network and practices and simulated the relief operation based on a flooding in the city of Magdeburg in Germany in the year 2013. Thus, the scope of the evaluation is restricted to a governmental crisis management organization and the transferability to international relief organizations is limited. However, grounding the simulation model with the reference task model developed with over 30 relief organizations promise to be applicable to other organizations like international NGOs or UN organizations. Several of the involved tools were already applied at other organizations like a Red Cross Society or an international operating NGO (see e. g. Widera and Hellingrath 2011, 2016).

The integrated tool suite consists of four components: (1) KeepOperational, (2) U-Fly/3K, (3) ZKI-Tool and (4) HumLog:

(1) KeepOperational is a web-portal developed by the German Aerospace Center (DLR). KeepOperational visualizes the current traffic situation using different traffic sources. The traffic data can be used as basis to simulate and predict traffic and for supporting the decision process for traffic management actions (e.g. routing) in case of an incident. KeepOperational also involves SUMO – a microscopic and open source road traffic simulation. It provides transport and traffic information for emergency services (e.g. current traffic situation, routing advice, traffic prediction, scenario modelling, Presentation of the timely reachability in dependency of the current traffic situation, display of aerial images).

(2) U-Fly/3K is a ground control station (GCS) for Remotely Piloted Aircraft (RPV). The capabilities include mission planning and evaluation for single RPAS or swarm formations. U-Fly receives aerial sensor data, processes and evaluates sensor data, and dynamically adapts RPAS missions to newly received information. The 3K camera system is integrated into the RPV D-CODE and sends down georeferenced images and derived image products to the GCS. Provision of airborne imagery data. Information on damaged infrastructure can be extracted from the gathered data and traffic data can also be extracted.

(3) The ZKI-Tool is provided by the Center for Satellite Based Crisis Information (ZKI) at the German Remotes Sensing Data Center (DFD) at DLR. ZKI provides a 24/7 service for the rapid provision, processing and analysis of satellite imagery during natural and environmental disasters, for humanitarian relief activities and civil security issues worldwide. The tool provides flood impact information, e.g. water masks, or information about affected infrastructures derived from aerial and satellite imagery; it is used as an input for tools on traffic management and logistics support (e.g. KeepOperational). Additionally, it provides 3-D visualization and GeoPDF for crisis management organizations.

(4) HumLog itself is a tool suite containing three modules: (i) HumlogEM is a modelling tool able to support various modelling languages (see e.g. Widera et al. 2013). It can be used for the application of reference models as well as for model reporting and pattern search. (ii) HumLogSIM is an AnyLogic-based simulation environment allowing a multi-method (discrete event, agent based, system dynamics) simulation. The network structure and the logistics processes of relief chains are mapped, resulting in organization-specific process models considering all relevant organization levels. The process models will be then used to adjust the existing humanitarian logistics simulation environment in the simulation model in AnyLogic. Appropriate parameter variations of the simulation model are then executed within a simulation study which is then analyzed by utilizing the (iii) humanitarian logistics performance measurement system HumLogBSC (see e.g. Widera et al. 2015, Widera and Hellingrath 2016).

The tool suite was applied in the following procedure: ZKI extracted crisis information from satellite and aerial imagery (e.g. flood layers, flood impacts) and provided 2-D and interactive 3-D cartographic solutions (map products and video animations) for the THW volunteers. By these means, the decision making processes were supported by an increased situational awareness as well as a damage and needs assessment. Additionally, the extracted crisis situation information was shared with KeepOperational. An airplane flew in advance of the experiment over the affected area to collect airborne imagery. The imageries and extracted traffic and crisis information were provided to KeepOperational. KeepOperational uses the provided information of U-Fly/3k and ZKI-Products as well as traffic data information from other sources to recommend route options for emergency vehicles by considering current traffic infrastructure, information of the traffic situation and infrastructure or a traffic prediction & simulation. The gathered traffic and routing information was finally integrated into the simulation environment HumLogSIM which evaluates different scenarios and network settings based on the stored process models (e.g. material flow calculation, procurement analysis, scheduling, bottleneck analysis, cascading effects). The architecture of the tool suite is depicted in Figure 3.

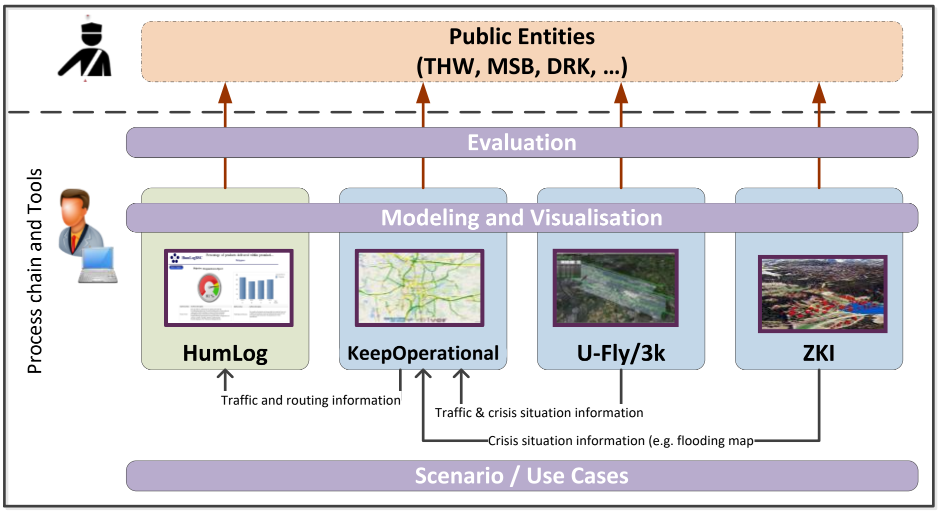

Figure 3. Toolsuite Architecture

The data of the simulated scenario were based on the existing THW network (e.g. standard operational procedures or location and vehicle information), recorded data (e.g. satellite imagery, aerial imagery) and event logs (e.g. scheduling of volunteers, demand orders). After continuous rainfall over several days the major rivers and its tributaries of Southern and Eastern Germany have reached their banks and became in danger of flooding adjacent areas. The city expected the prospect of a major flooding of large parts of the city area and has started emergency preparations for the event. The civil protection agency identified the endangered areas and affected population as well as the critical infrastructure of the city. The experiment was executed as a purely table top exercises, i.e. completely simulation-based.

We have recorded and analyzed quantitative and qualitative data. The generated results were presented to the professional responders, who expressed high interest in the provided solutions and confirmed an added value to their legacy systems and procedures. A detailed overview of the evaluation approach and the results can be found in Detzer et al. (2016). In particular, the participants perceived the provided solutions as a suitable solution for the actual transport and logistics tasks and processes. Besides, several improvements were identified with regard to technical and functional aspects of the tool suite. It was stated by the practitioners that the proposed solutions are beneficial for the THW volunteers regarding certain conditions:

- performing operation in unknown areas,
- performing tasks with considerably calculation effort,
- performing nationwide operations,
- performing complex tasks with many alternative decision choices.

Regarding the dimensions of agility, the evaluation showed that the following improvements could be established by the tool suite:

- Detection: Especially the KeepOperational feature of displaying the current traffic situation has been perceived as very good. In combination with HumLogSim’s route planning feature, it has been capable of improving situation awareness (cf. Figure 4).
- Adaption: It was realized that the solutions provide a relevant data-driven basis for decision making, because fast allocation and evaluation of alternatives was supported. Especially regarding

transportation tasks, the volunteers perceived this as useful. Nonetheless, it has been stated that the usage of the provided solutions benefits at the level "management and communication". During the experiment it was noticed, that the benefits of the solutions below this level are limited for the volunteers.

- Reactivity: In order to understand the impact of the tool suite, a control group was carrying out the same tasks in a traditional way. At the beginning of the experiment, it was noticed that the tool group compared to the control group needed more time to complete the given tasks, especially in performing easy and common tasks they are used to. The main reason for the time delay is that the volunteers received only a very rough coaching on how to use the tool suite. The performance in terms of time and accuracy of the results increased with an increase of the difficulty of the tasks.
- Effectiveness: The tool suite collects data that allow tracking of each transport and assessing measurements such as speed, capacity utilization etc. These features have e.g. also been used to evaluate the tool group's performance during the experiment.

Overall, the results from the qualitative data approve the results from the quantitative performance analysis. The professional responders declared a potential benefit for the tool suite and expressed their interest in applying it in their daily work. The tool suite has been approved as suitable to be used in an operation by the volunteers (cf. Figure 4).

However, several limitations were identified. The results' regarding usability differs between the proposed solutions. The operation of HumLog was not seen as easy and the use was assessed between good and partly. The use of ZKI-Products and KeepOperational were evaluated between very good and good (cf. Figure 5). This difference in the usability is justified by the fact, that, HumLog is not designed for field staff but for a yet not existing THW system operator. The "tool" needs thus to be understood rather as a socio-technical change of the current standard procedure. The suitability and relevance was confirmed for all components. Almost all questionnaires stated that they could manage the tasks more easily, that they could finish the tasks faster due to a better situation awareness. An interesting observation has been made regarding the (technical) connection of the tool components. A deeper integration was expressed here. Another limitation was identified in an additional mobile interface of all deployed components. Finally, the handling of the solutions and the data visualization and accessibility should be further ensured improved.

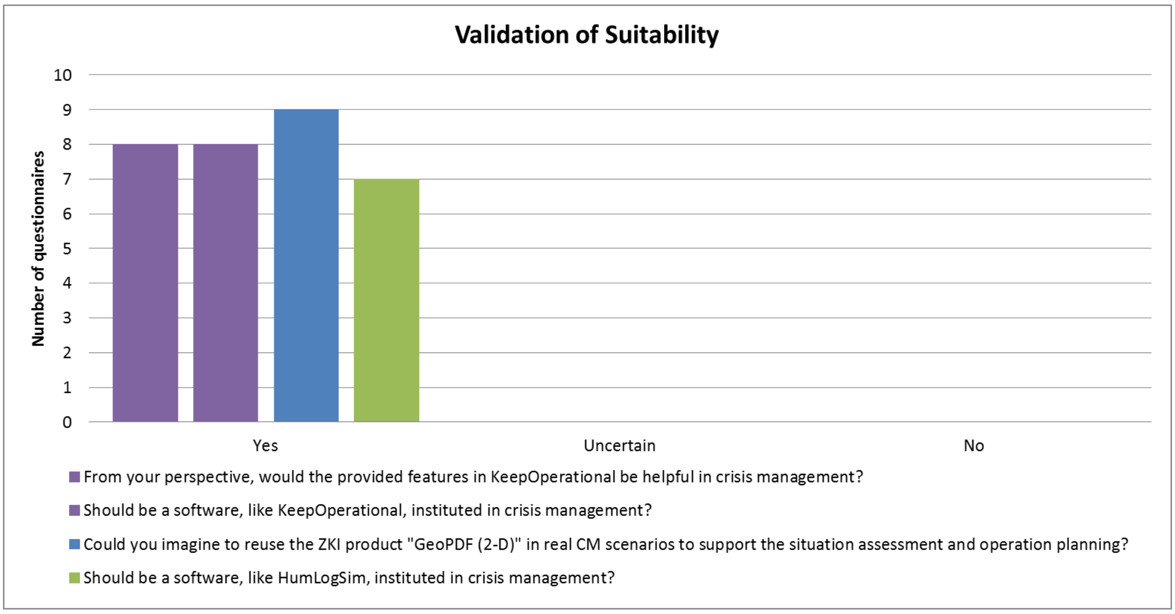

Figure 4. Validation of Suitability

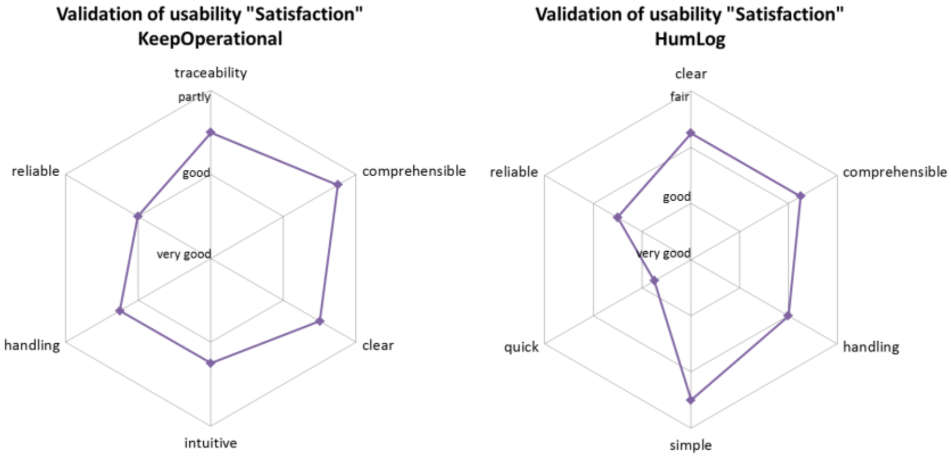

Figure 5. Validation of Usability

CONCLUSION

Logistics and transport planning can be described as a main driver for effective relief operations. In decision makers' practices both tasks are often perceived as directly inter-related and its execution is based on intuition and individual experiences of the involved staff. However, the available information systems address those needs inadequately because they tend to focus only on particular tasks for a particular sequence. Besides, those tools mostly use optimization approaches and seem to relieve final decisions of the practitioners. These circumstances lead to a poor acceptance of promising innovations and improvements of those truly challenging tasks in relief operations. We proposed and evaluated an integrated approach of logistics and transport planning which connects planning horizons and the inter-related tasks. The tabletop exercise revealed a relatively high acceptance by the practitioners and it has shown a direct impact on the logistics performance. Additionally, a couple of limitations were identified, especially in terms of embedding new practices into standard operational procedures, the usability of several tool suite components as well as their integration. We identified specific adjustments of the developed tool suite with regard to the given feedback. The next steps must consider further iterations of development and testing. For the purpose of testing it will become necessary to deeper investigate appropriate application scenarios as well as to analyze and evaluate new operational practices in close loops with the practitioner organizations. These lessons learned are based on the confirmed assumption that only a socio-technical approach promises to unfold the available benefits to improve crises management practices.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 607798. Moreover, the experiment presented in this paper would not have been possible without active support of the THW employees and volunteers. Finally, we thank the DRIVER "Logistics Management and Transportation" experiment team that has been working together for months in order to prepare, conduct and finally analyze the experiment. (*)

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Assessing Vendor Managed Inventory (VMI) for Humanitarian Organizations

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ABSTRACT

Logistics activities are of high importance for the success of a humanitarian operation and can be responsible for up to 80% of its costs. Vendor Managed Inventory, a concept successfully applied in commercial logistics, might be a possibility to enhance the effectiveness of humanitarian logistics operations. However, there is a lack of an appropriate assessment of the VMI applicability for a humanitarian organization. We propose an adjusted VMI Readiness Score for humanitarian organizations, a tool adapted from a commercial context for the specific requirements of humanitarian scenarios, to gain a general impression of the suitability of VMI. The tool is applied exemplary to the IFRC and the result indicates that it is worthwhile to further investigate the applicability of VMI for humanitarian organizations.

Keywords

Humanitarian Logistics, Vendor Managed Inventory, Humanitarian Supply Chains

INTRODUCTION

The number of disasters and the severity of their consequences have increased for the last years. Disaster management and humanitarian logistics are important to be capable of an effective response. The question whether concepts which have been well-tested in commercial logistics are applicable to the humanitarian sector arises (Bölsche, 2009). Theoretically, the concept of a Vendor Managed Inventory (VMI) promises to be able to cope with many challenges of humanitarian logistics because it supports the relief organization to focus on their core competence being providing help. If a customer and a vendor engage in a VMI-based relationship, the responsibility for the time and amount of order is transferred from the customer to the vendor. Benefits such as reduces costs or an increase in goods availability would also be of advantage in humanitarian scenarios (Bookbinder et al., 2010).

This paper aims at providing a method to examine the potential benefit of VMI application for humanitarian logistics in general. Before investing time and costs to investigate quantitatively and technically how the VMI concept could be implemented in a humanitarian organization, it is beneficial to first assess whether it is suitable on a rather level. To support a general assessment of VMI, we propose a humanitarian-specific adaption of the VMI Readiness Score, which was originally developed to judge the suitability of VMI for organizations in a commercial context. Based on a literature analysis on VMI and its applicability in humanitarian logistics, we identify, analyze, and adjust an appropriate assessment method as a starting point to evaluate case-specific VMI fittingness. To evaluate the concept, we apply the VMI Readiness Score exemplary for the International Federation of the Red Cross (IFRC) based on available documents on organizational structure, procurement processes and other relevant data.

The first section describes the challenges of logistics in the context of humanitarian operations and the basic concept of VMI. In the main part, we present and discuss the adjustment of the VMI Readiness Score. A Use-case based application of this Score for the IFRC will be presented to reflect benefits and limitations. Finally, a conclusion summarizes the findings and points out limitations as well as future research possibilities.

LOGISTICS IN THE CONTEXT OF HUMANITARIAN OPERATIONS

Humanitarian logistics describes "(…) the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people" (Thomas and Kopczak, 2005). Overall, the term subsumes a wide range of tasks and does not denote a definitive field of activity (Blecken, 2010).

Logistics is a key factor for the success of a humanitarian operation. Up to 80% of the occurring costs can be ascribed to logistics activities (Blecken, 2010). Only since the South-east Asian tsunami in 2004, the topic of humanitarian logistics has gained more attention and the number of corresponding publications has increased significantly (Kunz and Reiner, 2011). One important reason for this paradigm change is uncertainty in the following areas: Needs for goods and services, personnel, equipment, stock levels, financial means, number of affected people, state of infrastructure etc. Short lead time – contingent on the often sudden onset of disasters – and lacking initial resources are further challenges needed to be addressed by decision makers, who can themselves be a challenge due to their high number and variety (Ortuño et al., 2013). The number, type and severity of the arising challenges are dependent on the type of the occurred disaster, focus and location of the organizations and the environment of further stakeholders (Kovács and Spens, 2009).

The uppermost aim of humanitarian logistics is to save human life and alleviate suffering. To do so, humanitarian organizations operate across the disaster management cycle per Figure 1, which can be described by the four phases: mitigation, preparedness, response and recovery (Holguín-Veras et al., 2012). Because humanitarian operations are encompassed by various requirements, each stage consists of specific tasks and functions. However, the boundaries between the four phases are blurry and the four phases are overlapping and interrelated (Blecken, 2010; Kovács and Spens, 2009; Ortuño et al., 2013).

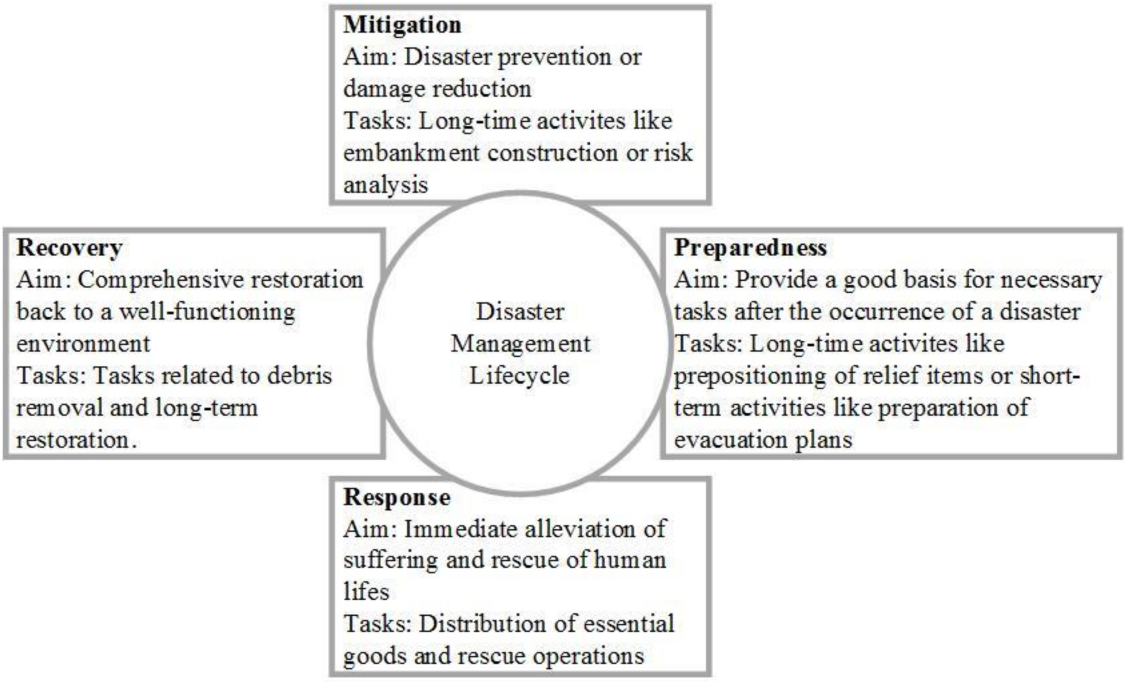

Figure 1. Disaster Management Lifecycle
(Own compilation based on Altay and Green, 2006; Celik et al., 2012; Ortuño et al., 2013)

RELATED WORK

The Concept of Vendor Managed Inventory

VMI, also known as „continuous replenishment, automatic replenishment [or] supplier-managed inventory“ (Razmi et al., 2009), is a strategy for supply chain management and was established by well-known companies like Wal-Mart or Procter & Gamble in the 1980ies (Sari, 2008; Waller et al., 1999).

Information exchange and a reallocation of responsibilities are central points of the VMI concept. While traditional supply chains leave decisions about amount and time of replenishment to every single member, VMI is characterized by transferring this responsibility to the preceding supply chain member (Kannan et al., 2013). Consequently, the customer delegates the responsibility for his inventory and its management to the vendor. When applying the VMI concept, the customer is responsible for providing the vendor with every relevant and helpful information (“point of sale” data), which is enabling bilateral or global optima (Claassen et al., 2008). The question on the responsibility for creating demand forecasts varies in the literature. While some sources assign this responsibility to the vendor (e.g. Achabal et al., 2000) others name it as one of the customer’s tasks (e.g. Claassen et al., 2008; Kannan et al., 2013). Moreover, the vendor’s autonomy of decision can be limited by agreeing on a safety or maximum stock or a certain service level which needs to be satisfied. The compliance is then monitored by the customer and in case of exceeding the agreed level, the vendor can be inflicted on the vendor (Darwish und Odah, 2010; Razmi et al., 2009; Sari, 2008).

In the literature, different advantages of implementing the VMI concept are discussed, which are justified for example by simulation (e.g. Southard and Swenseth, 2008), mathematical models (e.g. Choudhary and Shankar, 2015) or empirical evaluation (e.g. Kauremaa et al., 2007). Advantages are possible in the following categories: more precise demand forecasts, improved inventory management, reduced costs and increased service level. These categories are mutually dependent and benefit from each other.

Apart from the advantages mentioned above, the implementation of VMI harbors different challenges. One of the greatest obstacles is the need to establish intensified and long-term, relationships between the customer and vendor, which is trusting and faithful enough to allow the necessary level of coordination, e.g. exchange of sensitive data (Claassen et al., 2008). Additionally, customer and vendor often use different KPIs to measure their success (Angulo et al., 2004; Darwish and Odah, 2010). Apart from that, technical aspects offer huge range for pitfalls. To guarantee an adequate information exchange, information and communication systems of both partners do not only need to fulfill the according requirements but also must be integrated. Adjustments of the systems may be needed and can be costly and time-consuming (Choudhary and Shankar, 2015; Watson et al., 2012). Furthermore, even if the exchange of information is succeeded, there is still the challenge to provide the right information at the right point in time and then process and use it in the right way (Angulo et al., 2004; Sari, 2008).

Overall it can be stated, that the concept of VMI is not a universally suitable strategy. A successful application of it is dependent on the demand process, the environment, in which the companies are operating, as well as the type of products produced by the vendor (Choudhary and Shankar, 2015). The negotiations regarding the legal setting, framework agreements, types and amounts of covered goods, process alignments, technical setups and implementations are time consuming and expensive for the involved partners. The planning horizon is of strategic nature limiting the flexibility of both parties.

Vendor Managed Inventory in the Context of Humanitarian Logistics

Even though various advantages have been identified regarding the usage of VMI in commercial logistics scenarios and therefore suggest that this approach might also be beneficial for humanitarian ones, there are only few existing sources dealing with this topic. Moreover, they state different opinions on the realizable benefits: On the one hand VMI is considered to not be appropriate as in the case of a disaster there would not be enough time to implement an adequate information exchange and good-enough forecasts (Bölsche, 2009). On the other hand, this conclusion neglects the existence of predictable turnover of relief goods distributed in ongoing projects of humanitarian organizations on recurrent disasters or midterm projects initiated in response to ad-hoc missions. One example is the United States Agency for International Development (USAID), which applies VMI in the context of their DELIVER PROJECT (Watson et al., 2012). Within this project, VMI is used to increase the supply chain’s performance and improve the availability of medical goods in developing countries. Especially in humanitarian operations, where only little forces are acting directly on-site, VMI can lead to a significant improvement. The usage of VMI allows on-site forces to concentrate on e.g. distribution work, and shifts the responsibility for logistics-related tasks to members of higher levels of the supply chain, who often have better suited skills. The resulting advantages are decreasing inventories and costs, reduced transport- and distribution costs as well as an increased product availability. Circumstances like possibly volatile programs, insecure financing, low-quality communication and information systems, highly variable demand or a lack of

trust are typical challenges. Nevertheless, operations by USAID show that these challenges can be overcome and that the usage of VMI in the context of a suited scenario can have major benefits for humanitarian logistics (Watson et al., 2012).
Having compared both examples and their converse opinions, it is remarkable that Bölsche (2009) uses a holistic viewpoint for the suitability assessment. Instead of using characteristics like type or cause of the disaster or the disaster's magnitude to distinguish different application scenarios, it is only differentiated between regional and central level. The question, whether VMI is suited for an application in a humanitarian scenario in general, is asked. This can be seen critically, since such a general examination does not reflect the manifold and individual challenges of humanitarian logistics scenarios.
It can be concluded that although the applicability of VMI needs to be assessed for specific humanitarian logistics scenarios (like one organization, a humanitarian network or a long-term project), there is so far no tool available to do so. Such a case-specific evaluation would allow the identification of benefits as well as the deduction of potential risks. Successful VMI examples such as presented by Watson et al. (2012) indicate the worthiness of a more detailed examination of specific application cases. Likewise, it is stated, that VMI is not the only possible improvement or solution and should not be regarded as a universal remedy. A decision on whether to apply or not the concept of VMI must be deliberately considered for every single case and should only be based on its specific circumstances.

VMI READINESS SCORE

Key driver for a successful application of VMI are mutual trust and information exchange. Both supply chain members, the vendor and the customer, must be committed to engage in a long-term and close relationship making it possible to share the necessary and often sensitive data. Since the advantages of VMI can only be achieved in collaboration, customer and supplier are highly dependent on each other. To make such a relationship work, not only trust but openness and honesty are necessary. Relationship, information, information- and communication-system quality as well as the intensity of information exchange are the four crucial factors for a successful application of the VMI concept (Claassen et al., 2008). In addition, it is advised to concentrate on class A and B products, i.e. products causing a large part of the cost while only being produced in a low quantity. After successful implementation class C products build potential for cost savings as well (Kannan et al., 2013).
Nonetheless, possible advantages of VMI have been sufficiently discussed in literature, while the question on the circumstances under which benefits occur, has been neglected so far. Therefore, NIRANJAN ET AL. (2012) developed a *VMI Readiness Score* that can be used to assess the general applicability of VMI for a given scenario. Following a literature research approach, they identified features, which are summed up in three categories: product-related, company-related and supplier-related.
Each of these features has been weighted by experts from research and industry. After assigning values from 0 (totally disagree) to 4 (totally agree) to each of the features, these values are multiplied with the feature's weight and summed up. The result gives an indication on the general applicability of VMI for the considered scenario. A value below 200 (resp. 50%) reveals that the application of VMI is not promising and a value above 300 (resp. 75%) suggests that VMI might be a suitable concept. If the value lies between 200 and 300 (resp. 50 and 75%), VMI should at least be considered as a serious alternative, as although not fulfilling every requirement, the considered scenario holds the capability to lead VMI to a success.
Having established the 15 features, the score has been validated with case studies in ten different companies. Employees of these companies have assigned values to the features and calculated the responding VMI Readiness Score. All results correspond to the actual situation, i.e. the framework allocates companies not applying VMI a respectively low value and vice versa. Among companies with a medium readiness score (between 50 and 75%), some using VMI and some not using it are situated (Niranjan et al. 2012). Table 1 offers an overview of the 15 identified features, their weight and a statement about whether they are controllable resp. improvable.
Overall, the VMI Readiness Score is a tool to get a company-specific indicator on the suitability of the VMI concept. Since the score calculation is only based on simple mathematics, it is easily applicable – e.g. by using a spreadsheet calculation - and consequently well-suited for a humanitarian context.

Product-related	**Company-related**	**Supplier-related**
Products are standardized, i.e. customization is minimal (7.07)	Transaction costs pertaining to purchasing are high (5.14)	High levels of trust and long term relationships with the suppliers exist* (7.72)
Products are repetitive, i.e. infrequent changes in product specification by customer (8.04)	Company revenues have been stable over the years, i.e. neither grown rapidly nor fallen (3.86)	VMI benefits are evident to both our company and our suppliers (7.07)

Products have a standard product identification throughout the supply chain* (6.75)	The company has no problem sharing inventory/forecast information with suppliers* (9.97)	Key suppliers constitute a high percentage of purchase orders* (5.14)
Demand variance is low (4.82)	Information and communication systems are good* (6.75)	Suppliers are willing to cooperate with a VMI initiative (8.68)
Demand is forecasted and stock levels are closely monitored* (7.40)	Purchasing is a core competence of the organization (7.07)	The company's information system is integrated with the suppliers* (4.50)

Table 1. VMI Readiness Score (feature weight in brackets; * = feature is controllable/improvable)

Adapted VMI Readiness Score for Humanitarian Organizations

The original VMI Readiness Score has been developed for a commercial setting. Due to fundamental differences between commercial and humanitarian logistics (see Widera and Hellingrath, 2011), it has to be adapted to the specific requirements and challenges of the application domain. Consequently, every feature must be critically reflected regarding its applicability for the specific characteristics of humanitarian logistics. Due to the nature of VMI, the features differently affect the upstream supply chain focusing the information and financial flows and the downstream direction, mainly covering the subsequent material flows. Moreover, the special characteristics of humanitarian scenarios also affect the importance of each feature. Thus, even if a feature is applicable to a humanitarian context, it might be necessary to adjust its weight.

Product-related features

Product-related features mainly contain statements about the characteristics of the products or the demand. The judgement of whether a product is suitable for the use of VMI or not is therefore limited to the product and demand and not directly related to the aims and obstacles of the setting. Only the suitability of the products is analyzed and no attention is payed to the surrounding circumstances. Consequently, it seems that no adaption is needed to apply this section to a humanitarian scenario. It might be the case that different sets of relief items are needed in different disaster types, but in general, the portfolios of relief goods are organization specific, e. g. humanitarian organizations focusing on medical relief have a predefined set of standard items to be deployed in operations. This does not mean that the delivered supplies always need to be identical: the proportion of bandaging material and medications might vary between different disaster types, but the suitability of VMI has to be tested in context of an average mix of identified demands. Thus, average numbers (costs, amounts) of supplied items in a set time frame need to be considered in this category.

Organization-related features[1]

In contrast to the products-related features, a humanitarian setting leads to specific requirements for an organization. For example, the importance of a fast delivery is much higher than in a commercial setting whereas costs become less relevant. Therefore, the feature "The company revenues have been stable over the years i.e. neither grown rapidly nor fallen" may be omitted. Nevertheless, costs play another role in the sense that it is necessary to ensure a sufficient funding of humanitarian operations. So it is sensible to replace this feature with one that asks about reliable funding (Watson et al., 2012). The same argumentation indicates a reduction of the weight of "Transaction costs pertaining to purchasing are high". The relation of transaction costs to purchasing activities are still relevant, but as with costs in general this aspect becomes less important in a humanitarian setting. Another aspect which is not considered in the features is the capacity to manage and maintain information systems. Information systems themselves are supposed to be judged regarding their quality but no statement is made about whether organization members are capable of adequately handle them. Therefore, the feature "Information and communication systems are good" will be extended by adding "and there is sufficient knowledge on how to handle them".

Supplier-related features

The supplier-related features concentrate on the trust between the company and its supplier and on the agreement to use VMI. These aspects are requirements, which are independent from the environment companies are operating in and fundamental for the successful application of VMI. Consequently, the stated features do not have to be changed to make them applicable to a humanitarian scenario and their weight should remain the same

[1] The heading of this feature section needed to be changed, since it is not suitable to call humanitarian organizations "companies".

to still indicate the high importance of a profound relationship between the organizations operating under VMI.

Product-related	Organization-related	Supplier-related
Products are standardized, i.e. customization is minimal (7.07)	Transaction costs pertaining to purchasing are high (2.54) ↓	High levels of trust and long term relationships with the suppliers exist* (7.72)
Products are repetitive, i.e. infrequent changes in product specification by customer (8.04)	Funding for procurement is reliable –availability of donor funds or government funds (4.51)	VMI benefits are evident to both our organization and our suppliers (7.07)
Products have a standard product identification throughout the supply chain* (6.75)	The company has no problem sharing inventory/forecast information with suppliers* (10.62)	Key suppliers constitute a high percentage of purchase orders* (5.14)
Demand variance is low (4.82)	Information and communication systems are good and there is sufficient knowledge on how to handle them* (7.4)	Suppliers are willing to cooperate with a VMI initiative (8.68)
Demand is forecasted and stock levels are closely monitored* (7.40)	Purchasing is a core competence of the organization (7.72)	The organization's information system is integrated with the suppliers* (4.50)

Table 2. Adapted VMI Readiness Score (feature weight in brackets; * = feature is controllable/improvable)

Case-based Investigation

The adapted VMI Readiness Score is deployed to evaluate the applicability of VMI for a humanitarian organization. The International Federation of Red Cross and Red Crescent Societies (IFRC) is used as an exemplary case. The assessment of the different statements is based on publicly available reports published by the IFRC[2], among them their procurement catalogue, dedicated procurement reports as well as reports describing their work during various humanitarian operations. According to them, each features obtains a value between 0 (statement cannot be supported at all) and 4 (statement can be fully supported). It is important to notice that not all features can be answered solely based on these sources. Especially with regard to supplier-related features, feedback from an expert knowing the IFRC would be helpful. Whenever the sources for a feature's assessment are not sufficient, the medium value of 2 will be assigned to influence the score neither negatively nor positively.

Products are standardized, i.e. customization is minimal

This statement is valid for the goods typically distributed by the IFRC, which can be viewed e.g. via the Emergency Item Catalogue (IFRC and ICRC, 2009). Those are fundamental relief items and cannot be customized. Also product-sets like dedicated baby-kits are composed of standard items. Consequently, not the goods themselves but their assortment is personalized.

Products are repetitive, i.e. infrequent changes in product specifications by customer

Also this statement can be confirmed by the IFRC reports. Product assortments can be changed according to actual needs but as mentioned before, an adjusted set is still composed of standard products.

Products have a standard product identification throughout the supply chain

The Emergency Item Catalogue (IFRC and ICRC 2009) not only gives an overview of available relief items but also assigns a distinct number to each of them. Since all members of the supply chain, i.e. the IFRC as the parent organization and various national societies, use the catalogue, it can be assumed that the product number is used as a reference in the whole supply chain.

Demand variation is low

This statement cannot be supported. During a humanitarian operation the demand for certain relief goods can vary because of numerous reasons, e.g. subsequent catastrophes or changing weather conditions. Moreover, in times between two different humanitarian operations, there is a high demand variation.

Demand is forecasted and stock levels are closely monitored

[2] Publications and reports issued by the IFRC can be found here: http://www.ifrc.org/publications-and-reports/

The IFRC already conducts demand forecasts (cf. Chomilier et al., 2000; IFRC, 2011) and have also contributed to and will use the results of the paper by Everywhere et al. (2011) dealing with the predictability of humanitarian demand. Still, it cannot be said whether these forecasts are detailed enough to serve as a basis for the usage of VMI. Regarding the monitoring of stock levels, the statement can be supported. The arrival and inventory level of all relief goods can be controlled with the help of a Commodity Tracking System (Chomilier et al., 2000).

Transaction costs pertaining to purchasing are high

Neither the independent auditor's report (KPMG, 2016) nor other publicly available sources state something about the height of transaction costs. Consequently only the neutral value of 2 can be assigned to this feature.

Funding for procurement is reliable –availability of donor funds or government funds

Among the IFRC publications there are reports specifically listing the coverage of issued emergency appeals, i.e. how much of ne estimated needed budget has been covered by donor response in cash, kind and services. These numbers show that the amount of donor coverage varies depending on continent but the overall yearly average of 2014 to 2016 has varied between 45% and 73% coverage. So while funds are available, they are not sufficient to provide the entire budget needed for emergency operations.

The organization has no problem sharing inventory/forecast information with the suppliers

The IFRC has set up different requirements that future suppliers need to fulfill and reviews them accordingly. If a supplier passes this screening, a basic consent in values is ensured. Nevertheless, the need for detailed contracts and ongoing evaluation of the supplier show that the IFRC does not fully trust its suppliers and the sharing of sensitive information might be difficult. Overall, this feature can be assessed only based on insufficient information. The opinion of someone more familiar with the IFRC would be of benefit.

Information and communication systems are good and there is sufficient knowledge on how to handle them

The improvement of the applied information systems has been part of the 5-year strategy "Logistics 2015" (IFRC, 2011). Also the "Plan and Budget 2016-2020" includes a budget of 4 million Swiss Francs to invest in telecommunication and information systems (IFRC, 2015). This and the fact that in general information systems for humanitarian organizations are in the need of improvements results in a low value for this feature.

Purchasing is a core competence of our organization

The IFRC and their national societies aim at supporting people affected by disasters. The purchase of relief items is an important part in order to fulfill this aim. However, while purchasing is of high importance, it cannot be regarded as a core competence on its own. This is rather to provide help and can only be achieved in interaction with other ones.

High levels of trust and long-term relationship with the suppliers exist.

The IFRC has contracts with different suppliers and no general assessment of this statement is possible. The relationships are all based on a consent on the IFRC's values but still the level of trust seems not to be high enough to fully support this statement.

VMI benefits are evident to both our company and our suppliers.

It is difficult to judge this statement as there is no publication or discussion on the application of VMI for the IFRC yet. It still can be assumed, that the existing collaboration and communication would lead to both parties, the IFRC and the national societies, recognizing the benefits of VMI equally.

Key suppliers constitute a high percentage of purchase orders.

The IFRC maintains contracts with various suppliers. Unfortunately, there is no source listing these suppliers or the amount of items they deliver to the IFRC publicly available. Consequently, in order to evaluate this statement an expert's opinion would be necessary and now only a neutral value of 2 can be assigned.

Suppliers are willing to cooperate with a VMI initiative.

There is no information available on the willingness of the IFRC to implement the VMI concept. Whether a supplier would agree to implement VMI depends on the volume of goods ordered by the IFRC and on other factors such as possibly existing experiences with VMI. Unfortunately, there are no information on this aspect.

The company's information system is integrated with the suppliers.

There is no information available on the integration of information systems between the IFRC and its suppliers. Again, only a neutral value of 2 can be assigned to this statement.

Feature	IFRC-Value
Product-related	
Products are standardized, i.e. customization is minimal (7.07)	4
Products are repetitive, i.e. infrequent changes in product specification by customer (8.04)	4
Products have a standard product identification throughout the supply chain* (6.75)	3
Demand variance is low (4.82)	0
Demand is forecasted and stock levels are closely monitored* (7.40)	2
Company-related	
Transaction costs pertaining to purchasing are high (2.54)	1
Funding for procurement is reliable –availability of donor funds or government funds (4.51)	1
The company has no problem sharing inventory/forecast information with suppliers* (10.62)	3
Information and communication systems are good and there is sufficient knowledge on how to handle them* (7.4)	1
Purchasing is a core competence of the organization (7.72)	2
Supplier-related	
High levels of trust and long term relationships with the suppliers exist* (7.72)	3
VMI benefits are evident to both our company and our suppliers (7.07)	2
Key suppliers constitute a high percentage of purchase orders* (5.14)	2
Suppliers are willing to cooperate with a VMI initiative (8.68)	2
The company's information system is integrated with the suppliers* (4.50)	2
RESULT	**231.18**

Table 3. Adapted VMI Readiness Score applied to the IFRC

Based on the above-described reasons, values can be assigned to every feature (cf. Table 3). Their weighted sum is 231.18 out of 400 resp. 57,8%. This percentage falls into the second category, i.e. a medium VMI readiness score. Organizations within this category can neither be judged as completely suitable nor as unsuitable to implement VMI. Consequently, the score indicates that a more thorough and organization-centric examination of the applicability of VMI is worthwhile but still needs to be conducted.

CONCLUSION

The adapted VMI Readiness Score turned out to be a user-friendly and comprehensive tool to give an elementary assessment on whether the concept of VMI is suitable for a humanitarian organization or not. Possibly realizable cost and inventory reductions coupled with increased availability of goods could lead to a better dealing with the challenges of a humanitarian operation. The exemplarily application shows that VMI in general could be treated as a possible alternative to currently implemented logistics strategies at the IFRC. Nonetheless, the Score can only serve as a first judgement or indication and an applicability of VMI needs to be evaluated further. One major drawback is that the disaster type an organization operates in, is not considered in the Score specifically but in average. Thus, depending on the investigated time frame (mainly regarding the product-related feature), the suitability of VMI might change. So future research could think about how to integrate this aspect into the Score, i. e. defining a representative random sample of historical data. Moreover, it has to be kept in mind that the exemplary case is based on publicly available information which sometimes have been incomplete or hard to interpret, so that assumptions had to be made. Especially in the category of supplier-related features, a lack of information resulted in high difficulties to judge the statements. Future steps would therefore be to involve the practitioners, recalculate the score based on more detailed information and then decide on whether to further investigate the applicability of VMI. During the writing of the paper, a detailed application of the Score in combination with a quantitative analysis at an interested humanitarian organization is ongoing. Overall, the results emphasize that more research should deal with the topic, since VMI has shown to be a possible logistics strategy to improve humanitarian logistics.

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Sustainable Performance Measurement for Humanitarian Supply Chain Operations

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ABSTRACT

This paper proposes a performance measurement definition to consider sustainable development principles in the humanitarian supply chain operations (source, make, deliver). Previous research has shown the challenge for humanitarian organizations to consider the three sustainability pillars people, planet and profit in their decision-making processes. Based on field research with the International Federation of the Red Cross and Red Crescent (IFRC) and a literature review on humanitarian performance measurement and sustainability, we define a set of criteria, objectives and Key Performance Indicators that translates sustainability concepts to concrete humanitarian operations. Based on the Triple Bottom Line approach, the environmental and social dimensions are added to the economic dimension, which is standard in HSC literature and practice. The aim of this study is to set the basis for a Decision Support System (DSS) in operations planning.

Keywords

Humanitarian Supply Chain, Key Performance Indicators, Triple Bottom Line, sustainability

INTRODUCTION

The main objective of Humanitarian Supply Chains (HSC) is to ensure the distribution of relief items to beneficiaries when a humanitarian disaster occurs. As resources are scarce and budgets limited, performance measurement has become critical to achieve the aims of humanitarian operations (saving lives and reducing human suffering), and to secure donor funding (accountability) or economic viability. Typically, the HSC refers to criteria such effectiveness or efficiency to measure the success of their operations. This approach permits the HSC to maintain their position (order qualifier) in the humanitarian response "marketplace".

Beyond these economic considerations, the growing urgency of switching to sustainable development is gaining ground in public opinion. Major events like the Millennium Development Goals (MDGs), the 2030 Agenda for Sustainable Development (ASD), or the 2016 World Humanitarian Submit (WHS), promoted by the United Nations confirms this global trend. MDGs were the eight international development goals for 2015 established following the Millennium Submit, with an emphasis on social and environmental sustainability. The WHS committed to engage with local communities to enhance resilience. And the ASD emphasized the need to reduce disparity (eradicate poverty) as a major requirement for sustainable development. Thus, sustainability is a relevant topic that affects all organization functions, in all the sectors including public administration, corporate sector and non-profit.

Sustainability concept, and the links that sustainability has with supply chain operations, strongly suggest that sustainability is a requirement to do business in the twenty first century (Carter & Liane Easton, 2011). Also in Humanitarian Organizations, the concern for the long-term impact of operations is growing. Indeed, to maintain a competitive position (order winner), considering sustainability becomes fundamental.

> "We happily endorse the 2030 Agenda, and our network stands ready to partner with governments, UN agencies, civil society, the corporate sector and communities themselves to turn this ambition into a reality."
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> New York, 25 September 2015

Several papers call for research on the sustainability of humanitarian response (Ira Haavisto & Gyöngyi Kovács, 2014; Kunz & Gold, 2015). However, practitioners do not have the tools to evaluate the impact of HSC operations. Kovacs highlighted the need to find a link between the short-term aims on operational performance and the long-term impact. Moreover, literature states that equity (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010) and sustainability (Ira Haavisto & Gyöngyi Kovács, 2014) are overlooked, although they are essential for aligning operational with longer-term objectives of humanitarian aid.

Consequently, the research question is: how to define and measure sustainability performance at the HSC operations?

This study aims at defining a set of performance criteria to asses the sustainability of HSC operations, the related objectives and Key Performance Indicators (KPIs) to quantify the impact based on the widely accepted triple bottom line (TBL): profit, people, planet. By performance criteria we mean the principle, by witch an activity will be measured. The objectives are the relation between the performance criteria and the aim of the organization. And the KPIs are the performance measurement related to each criterion (and objective). In other words, we address the problem of translating sustainable development principles into HSC decision-making.

This research contributes to the HSC and sustainability literature by merging both disciplines in a concrete and practical case. The proposal can be used as a reference by both practitioners and academics for HSC decision-making and for further research, respectively.

Approach & Research methodology

Once the research question was formulated, we started from a literature review on sustainable supply chain to obtain an overview of best practices and state of the art of sustainable performance. We reviewed also the existing literature on HSC and used previous field research observations to identify the performance criteria that humanitarian organizations consider (or would like to consider), aligned with their objectives as well as related KPIs. Field research was conducted on September 2015 at the Americas and Caribbean (A&C) IFRC Regional Logistic Unit (Panamá RLU). Then, we organize the findings per TBL dimensions to have a mapping of potential performance criteria, objectives and KPIs for sustainable HSC.

The Sustainable Supply Chain performance state of the art aimed at finding an accepted sustainable performance definition. As long as sustainability is a trending topic, the literature review was a qualitative selection of papers based on citation rate and non-exhaustive content analysis. Many authors use sustainability referring to Green Supply Chain, so we focused on papers with a wider definition of the term. Regarding HSC state of the art, even if it is not a new idea, we found few publications that refer to the concrete sustainable performance definition and measurement, like the dedicated book "Humanitarian Logistics and Sustainability" (Klumpp et al., 2015). We also considered humanitarian organizations reports and road maps to identify "best practices".

The HSC sustainability performance strategy was not the objective when the field research was conducted in 2015. The initial goal of the study was to support the IFRC HSC to become more cost-effective by developing innovative HSC approaches. With the aim of developing field-grounded research propositions, we based the research on empirical evidence (Eisenhardt, 1989). This consisted in studying the IFRC American and Caribbean (A&C) Regional Logistic Unit (RLU) case to identify weaknesses of the current activity model in terms of business processes, decision-making and information systems.

In practice, after conducting preliminary interviews with the Regional Logistics Development Coordinator (RLDC) of the IFRC A&C RLU, we designed guidelines, observations and mapping supports for semi-structured interviews and focus groups, inspired by previous field-research by the Disaster Resilience Lab (Comes et al. 2015). The fieldwork was conducted during a 10 days mission on October 2015 at the IFRC A&C RLU Panama site (office and warehouse). We interviewed all members of the RLU structure: Head, Service Officer, Procurement Officers, Logistic Officers and Warehouse Manager and Officers as well as the Panama Disaster Response Unit (PADRU) Coordinator.

The interviews and observations permitted to identify the current business processes and activities cartography, upcoming evolutions, and practitioner's needs, discussed on previous publications (Laguna Salvadó et al., 2016), which confronted to the literature review permits to build a Sustainable Performance Measurement for HSC operations.

This contribution is structured as following: First, a background section introduces the concepts of sustainability, sustainable CSC and sustainable HSC. Second, the proposal sustainable HSC criteria, objectives and KPIs are presented. We conclude with the "house of HSC sustainable operations" and further works are discussed, with the introduction to a potential use on a practical case.

BACKGROUND

The topic we address derives from the universal challenge of sustainable development. It is a wide challenge that has already tackled in other fields. In this section we review concepts that relate sustainable development to HSC performance by going through the ideas relevant to Sustainable Supply Chains.

Sustainability

Sustainable development (or sustainability) modern definition was drawn during Brundtland Comission on 1983: "*development that meets the needs of the present without compromising the ability of the future generations to meet their own needs*" (Brundtland, 1983). It is a highly debated concept, and depending on people and organizations perspective, sustainability is addressed or understood really differently. Brundtland's definition is quite philosphal, and it's difficult to asses how to fit HSC performance on it. Pojasek's (2012) proposed an operationalised definition, which considers sustainability as "*the capability of an organisation to transparently manage its responsibilities for environmental stewardship, social wellbeing, and economic prosperity over the long term while being held accountable to its stakeholders*" (Pojasek, 2012). This concept is usually addressed as Corporate Social Responsibility for business organizations.

In literature, however, it is widely accepted to present sustainability as the balance between the dimensions environment, society and economy. This dimensions are connected entities that follow the TBL model (e.g. Carter and Rogers, 2008). The TBL is a systemic approach developed on the mid 90's by John Elkington to"*captures the essence of sustainability by measuring the impact of an organization's activities including its profitability and shareholder values and its social, human and environmental capital" (Savitz, 2012)*. It stresses the need to achieve a minimum performance for the three dimensions. However, no consensus regarding the tradeoffs and synergies across the economic, environmental and social objectives has been state. Moreover, there is not a standard definition of each dimension. Here, we define the TBL dimensions as:

- Economy or "Profit": relates to cost and productivity considerations. An organization has to use its resources so that it can consistently produce an operational profit, and sustain its activities. In HSC specifics, the operational profit corresponds to alleviating suffering of affected populations by responding to their humanitarian needs.
- Social, or "People": relates to proper and favorable business impact for employees, population, and the area in which the organization conducts its activities.
- Environment or "Planet": relates to environmental impact. It attempts to benefit the natural setting as much as possible or at least do no damage and decrease the environmental effect.

The macro-economical definition of sustainability, and the three categorical dimensions can explain the sustainable development on a conceptual level, but do not provide much guidance on how sustainability shall be addressed on the context of Supply Chain operations.

Sustainable Supply Chain

Sustainable supply chain management (SSCM), is defined by Seuring and Müller (2008) as "the management of materials, information and capital flows as well as cooperation among companies along the supply chain while integrating goals from all three dimensions of sustainable development, i.e. economic, environmental and social, which are derived from customer and stakeholder requirement".

While analyzing supply chain sustainability disclosure, Okongwou identified TBL performance as one of the main drivers (Okongwu, Morimoto, & Lauras, 2013). For the economic dimension the elements identified by them were the financial value generated and distributed to the stakeholders and the proportion of spendings on supplier development ; Regarding the environment dimension, they identified the recycling materials ratio or the amount of energy saved due to efficieny improvement. And for the social dimension they identified the rates of injury, occupational diseas, and the incidents of forced and child labour, the rate of trined people and the rate of incidents related to product safety.

Performance measurement has been wide developed on recent years. However, Gopal and Thakkar (Gopal & Thakkar, 2012) argue that in the specifics of supply chain performance measurement, there is a large scope for research to address various issues such as characteristics of measures and metrics, benchmarking of measures and use of management practices. Nonetheless, sustainability performance measures are abundantly found in literature. Some of the key measures, even if defined using different words, are related to emissions, energy use, hazardous wastes and recycling for the environmental dimension; health, safety, training and child labour for the social dimension; economic value generation and distribution for the economic dimension. Looking at these performance measures, Okongwou observed that the responsibilities of a firm go beyond the wellbeing of its shareholders to include the environmental, economic and social wellbeing of its employees, suppliers, customers, local communities and the society in general (present and future generations). We can also find theoretical development contributions, like the framework developed by Beske (Beske, 2012), which integrates dynamic management theories into SSCM practices.

Sustainable Humanitarian Supply Chain

Humanitarian organizations purpose is to alleviate human suffering. For a long time, it has been understood that getting the right resources to the right place and at the right time is crucial for a successful relief response. Thus, humanitarian organizations have concentrated their efforts on HSC performance improvements. Looking at HSC operations, we identify many opportunities to improve the balance between effectiveness and efficiency to boost the economical dimension (Laguna Salvadó, Lauras, Comes, & Van de Walle, 2015). An example of these challenges is the contingency stock management of humanitarian organizations, which shows a significant misalignment with actual needs, producing excessive stock coverage and important bullwhip effects all along the supply chain.

The origin of those misalignments is the difficulty to align the HSC with disasters characteristics: ramp up time (slow / sudden onsets), cause (natural, human made, complex) or affected area (national/ transnational). In addition, the different disaster management phases (preparedness, response, recovery, mitigation) ask for different objectives and are partially overlapping. The decisions taken on one phase can conditions the success of next phases. E.g. it happens that the response phase compromises the ability of the system during the recovery phase (Kunz & Gold, 2015).

HSC from big humanitarian actors, like IFRC, UNHRD or NGOs must handle with an operating environment with requirements (scaling up and down, time and place uncertainties…). Previous research highlighted that HSC like the one of IFRC are facing structural evolutions, driven by the strategic objective to improve local response capacity, responsiveness, or cost-efficiency (Laguna Salvadó et al., 2016). The challenge is to align these evolutions with the sustainable development approach.

Today, an HSC can be described with two differentiated parts: the upstream HSC, that includes the private suppliers, the permanent network of Logistic Units, and the distribution flows till the field entry hubs; and the downstream HSC, that includes the field entry hubs to the final beneficiaries. We focus on this study on the upstream part.

The strategic trends of international HSC is to develop country-level contingency stocks (Laguna Salvadó et al., 2016). This evolution contributes to the long-term sustainability of HSC by empowering the local community (local capacity). However, this strategy presents some challenges like the increase of the costs: immobilized inventory or multiplication of warehouses. Thus, the interest to consider the holistic TBL approach.

The challenge to enhance sustainable HSC has been addressed on the literature, but most of the works addresses only one or two of the dimensions, and usually from a strategically point of view, or with focus on reporting and accountability (Carter & Rogers, 2008). Kunz and Gold (2015) have developed a framework of sustainable HSC where performance is conceptualized as flowing from a strategic reconciliation between relief organization's enablers (resources, capabilities and commitment) and beneficiaries' requirements, via an optimal supply chain design. In this paper, we therefore conceptualize HSC from an operational point of view. Based on SCOR reference model, the four main processes of the Supply Chain are: Plan, Source, Make, Deliver, Return and Enable. According to this model, Plan includes the processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production, and delivery requirements. However, Return and Enable processes are not yet considered in the HSC, so we do not address them on this works. Based on the business processes identified during the field research, the operational processes of the upstream HSC are then:

- Source (buyer-supplier relationship) that includes the processes that procure goods and services to meet planned or actual demand. Decision-making may be limited (or based) by framework agreements with suppliers that aim at reducing costs and ensuring the items disposal.
- Make (transformation processes) that is comprised of the processes that transform product to a finished

state to meet planned or actual demand. On the concrete case of HSC, make processes can relate to: (i) kitting activities (relief items consolidation). It is an operation that can reduce costs or improve performance (Vaillancourt, 2015), a,d (ii) the contingency stock management, which existence has became standard on humanitarian logistics to ensure first response capacity.

- Delivery (outbound logistics) that includes all processes, which provide finished goods and services to meet planned or actual demand.

Decision-making on supplier's selection, transport modes, routing, packaging, etc. puts Supply Chain managers on a privileged position to impact the environmental and social performance dimensions on positive or negative, as Carter and Easton emphasized (2011).

PROPOSAL

There is no universal definition of the three TBL categories; neither is there an accepted standard to measure it. Even if this lack of standardization can be seen as a weakness, it provides the possibility to adapt this general framework to any organization. The TBL approach comes from the for-profit sector, however, authors such as Remida or Kunz and Gold (Klumpp et al., 2015; Kunz & Gold, 2015) already made the assumption that it is a substantial part of the sustainable humanitarian system. In this adaptation process, the set of KPIs have to be identified by stakeholders, experts, and selected also according to the ability to collect the necessary data (Hall, 2011).

However, there is significant literature on the CSC and HSC that deals with one or several of the TBL dimensions. Based on literature, and field observations and practitioner's discussions, a set of criteria, objectives and KPIs is presented below.

Economic dimension

Traditional CSC performance is directed towards financial and operational indicators (Kunz & Gold, 2015). In HSC, the added value of operations is defined by accomplishing general humanitarian ambitions like "saving lives". To do so, the main criteria to evaluate HSC performance are generally effectiveness, efficiency, and equity (Gralla, Goentzel, & Fine, 2014).

Effectiveness is the capability of achieving the organization's target. On a "value driven" organization, the target will be to satisfy the customers needs. In HSC, donors ask for specific aims and target levels such as numbers of households that are provided with humanitarian relief items, shelter, or education. In HSC literature, the effectiveness objective usually corresponds to the demand satisfied. To measure it, different KPI are proposed like population coverage, order fulfilment, stock-out minimization, etc. By looking at the specifics of the three HSC processes, we define the effectiveness KPI of "source" as the effective replenishment, for "make", the strategic contingency stock level maintenance and for "deliver", the needs coverage (real demand) on time.

Equity considerations are still an exception in the humanitarian setting. We considered it as a complement of effectiveness if it is part of the value attended by stakeholders (donors and beneficiaries respectively): respect humanitarian principles. It also can be considered in the social dimension, as it has a direct link with societal wellbeing. In fact, equity it has been define as the intersection between people and profits (Carter & Liane Easton, 2011). Tzur measured the equity of HSC using the Gini Index (Tzur, 2016), a non-linear measurement of inequality. Others have used the deprivation cost approach (Holguín-Veras, Pérez, Jaller, Van Wassenhove, & Aros-Vera, 2013) or amount of suffering of the victims, or the disparity in demand satisfaction. Non-discriminatory distribution is an objective for the "making" and "distribution" processes (contingency stock maintenance, needs coverage). For the sourcing process, Field-observations at the IFRC shows that the objective is the respect of commercial fair competition.

Efficiency can be defined as the ability to avoid wasting resources to attain a target. In HSC, this dimension corresponds to the minimization of operations costs. Although making profit is not their objective, also non-profit organizations care about financial well being, since financial stability is crucial to their missions and survival. Cost KPIs have already been used as an objective function in many humanitarian distribution models (Benita M. Beamon & Burcu Balcik, 2008). Regarding the upstream HSC, Beamon and Balcik identified three dominating costs: the cost of supplies, distribution costs, and inventory holding costs. Other costs that can be considered are the kitting or consolidation costs (cost of building emergency item kits).

Thus, we propose the performance criteria, objective and KPIS as presented in Table 1 to define and quantify the economic TBL performance dimension of the HSC operations.

Table 1 Economy criteria, objectives and KPIs

Criteria	HSC Objective	Source	Make	Deliver	KPIs
Effectiveness	To satisfy demand on time			x	Needs coverage on time
			x		Contingency stock level
		x			Replenishment on time
Equity	Non-discriminatory distribution		x	x	Gini Index, deprivation cost
	Fair competition	x			Sourcing process quality
Efficiency	Cost reduction	x			Acquisition cost
			x		Holding cost
			x		Kitting cost
				x	Distribution cost

Environmental dimension

The environmental impact of increasingly globalized Supply Chains has been widely investigated since the 1990's . It has received huge attention and is the most developed concept of the TBL. "Green business", or the corporate's commitment to environmental protection has been demonstrated that leads to competitive advantages (Esty & Winston, 2009), as it seen as an opportunity for growth and profit. Thus, corporations have an incentive to publish more and more environmental policy statements, without any mechanism to control. This behaviour has generated some scepticism, and the creation of the "green-washing" term. One approach to face this skepticism in the light of many ineffective policies is the adoption of international standards like ISO 14001, which is implemented by many supply chain companies.

The CSC literature contends that logistic operations can influence particularly pollution (i.e. air, noise), and the conservation of resources (i.e. energy, water, etc.) (Murphy & Poist, 2003). Thus, we make the hypothesis that performance on those two areas constitute the environmental dimension on the specifics of HSC.

The objectives of measuring environmental pollution are mostly to reduce green house gas (GHG) emissions, and to manage hazardous materials resources. Hazardous materials are rare in HSC, but they may be present as part of the wastes (e.g., medical disposals, which was an important consideration in the Ebola response). However, we consider that its management is part of the downstream HSC, out of the perimeter of this study. Regarding GHG, the most widely used KPI is CO2 direct and indirect emissions, or the carbon footprint, coming from life cycle assessment approaches (LCA) (Baumann, 2011). Carbon emissions can be differentiated between two categories: stationary source (emissions from material processing, manufacturing, and warehousing) and non-stationary source (emissions from inbound and out-bound logistics) (Sundarakani, de Souza, Goh, Wagner, & Manikandan, 2010). On the green SCOR reference model best practices and performance metrics are suggested by each of the SCOR processes regarding pollution reduction and resource conservation. However, there is not an agreed framework for measuring i.e the environmental footprint of the supply chain.

The resource conservation objective is to reduce wastes like energy, water, packaging, etc. Resources are consumed all along the Supply Chain processes. Inventory immobilization (contingency stock) generates significant energy consumption especially in warm countries (air conditioning). Choices on the packaging or transportation mode may influence the quantity of packaging consumption.

We summarize the criteria on the environmental dimension in Table 2.

Table 2 Ecology criteria, objectives and KPIs

Criteria	Objective	Source	Make	Deliver	KPI
Pollution	Reduce GHG emission	x	x	x	Carbon Footprint
Ressource conservation	Reduce waste (energy, water, packaging…)	x	x	x	Resources consumption

Social

The Social dimension is the least developed in the TBL framework; it has been typically neglected in quantitative models (Brandenburg et al. 2014). In holistic social definitions, there are many criteria that can be found: education, equity and access to social resources, health and well-being, quality of life, and social capital.

We differentiate between internal and external factors. In HSC operations, internal factors are related to labour conditions and external factors with community empowerment. Both criteria builds the social sustainability performance as Table 3 shows.

Labour conditions are related with the 2030 ASD, which aims at enhancing prosperity by reducing poverty and economic disparity (wages), gender equality or decent work. The labour conditions objective for the HSC seeks to preserve health and security of employees, and ensure good conditions of work (Baumann, 2011).

One pillar of a humanitarian's organization strategy (HWS 2015) is to empower local communities with the aim of improving disaster resilience (amongst others) (Comes, 2016). Community empowerment can be seen as an external influence including contribution to employment and the creation of wealth. Many authors refer also to positive impact of local sourcing as an action of community empowerment (Kovács & Spens, 2011; Kunz & Gold, 2015) with a positive impact on regional economic development. Therefore, the current trend is favouring local sourcing wherever possible (Ira Haavisto & Gyöngyi Kovács, 2014).

Table 3 Social criteria, objectives and KPIs

Criteria	Objective	Source	Make	Deliver	KPI
Local communities empowerment	Local suppliers (and market) development	x	x	x	Local suppliers selection rate
	Create job and wealth	x	x	x	Local employment
Labor conditions	Ensure good conditions of work and preserve health and security of employees	x	x	x	HSE quality assessment

DISCUSSION & FURTHER RESEARCH

This study aims to translate sustainability concepts into a measurable HSC performance definition. The proposal set up concrete criteria, objectives and KPI set for analyzing the operations impact on the TBL approach. Figure 1 illustrates the proposed approach with the "House of HSC Sustainable Operations".

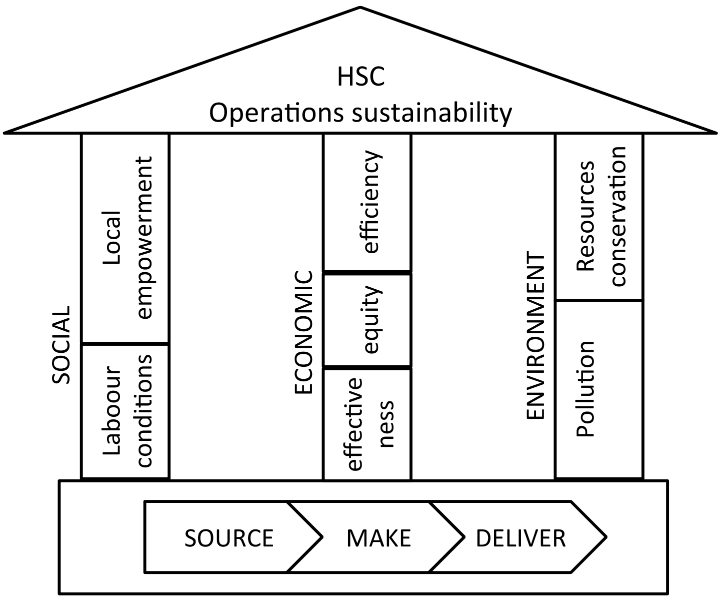

Figure 1. The House of HSC Sustainable Operations

The House of Sustainable Operations is based on the HSC operational processes: Source, Make, Deliver. Each pillar is built on the related sustainable performance criteria. To enhance an overall sustainable performance, the three pillars have to be balanced, so the roof is in equilibrium. This image reflects the importance of considering all the TBL performance objectives to enhance an overall sustainable performance. Carter and Rogers (2008) emphasize that organizations which pursuit to maximize performance of all the three pillars simultaneously will outperform organizations that only maximize the economic performance, or the ones that attempt to achieve high levels of social and environmental performance without explicit considerations of economic performance. Thus, enhancing sustainable performance may become an “order winner” even in the humanitarian sector.

One limitation of this proposal is the lack of consideration of sustainability as a holistic approach as suggested by many authors (Brandenburg et al. 2014; Carter and Rogers 2008; Okongwu, Morimoto, and Lauras 2013). The focus has been on the operations of the HSC, even if indirectly the strategy has been considered. Nonetheless, we have not considered the impact of other organizational process, for example, the design of the HSC, which has an impact on the TBL performance achievement. While in the past, a fragmented and siloed approach was typical, where Decision-Makers did not recognize the interrelationships between strategic of the overall organizational issues and operations. Thus, next steps will include working explicitly towards an integration of this proposal with the strategic processes of the HSC.

Planning HSC upstream operations

The main ambition of our proposal is to establish a basis to quantify the sustainability of HSC operations. One of the next steps is to implement this performance framework in a concrete case.

Even though HSC must deal with an increasing number of crises, the humanitarian setting is characterized by a lack of planning (Ira Haavisto, Gyöngyi Kovács, 2014). Moreover, sustainability assessments are typically used for reporting (ex posteriori), and not for planning or operational decision-making (a priori). Previous research highlights the potential of using DSS to improve decision-making capacity, especially on the future evolutions of the HSC, where the warehouse locations tend to increase (Laguna Salvadó et al., 2016). The development of Decision Support Systems (DSS) to coordinate the operations between the network members may facilitate efficient and effective flows of both physical and information, to quickly adapt to demand changes, and to introduce the TBL approach on the Decision making process.

The sustainable HSC performance suggested on this study is intended to be the base to develop DSS that permit to optimize the planning of the HSC operations regarding the TBL impacts. Today there are few (or no) performance measurement considered during tactical HSC decision-making. Therefore, we aim at developing a DSS that contributes to bridging the gap between academics and practitioners by considering field-grounded practitioners needs.

ACKNOWLEDGMENTS

The authors would like to thanks the IFRC for their support, and specially Mathieu Grenade (Asia Pacific IFRC Logistic Development Coordinator) for sharing his knowledge of the Humanitarian Supply Chain.

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New Technologies for Crisis Management

Social Media Visual Analytic Toolkits for Disaster Management: A Review of the Literature

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ABSTRACT

The past decade has seen a significant increase in the use of social media for disaster management. This is due especially to the widespread usage of mobile devices and also to the different data types and data formats that social media supports. In recent years, research in the area of social media visual analytics has also gained interest in the scientific community. Research in this area however, lacks a comprehensive overview on social media visual analytics for disaster management. Hence, this paper presents a synthesis of extant research on social media visual analytic and visualization toolkits for disaster management. We survey available literature on these tools with the goal to outline the major characteristics and features, and to examine the extent to which they cover the full cycle of disaster management. Our main purpose is to provide a foundation based on the current literature that can help to shape future research directions to enhance social media visual analytic tools for full cycle disaster management.

Keywords

Disaster, crisis, social media, visual analytics, disaster management.

INTRODUCTION

A disaster is any event that leads to a response beyond which the affected community can deal with locally (Adelman & Gray, 2009). Disaster management involves creating plans through which people can alleviate vulnerability to hazards and cope with disasters. Disaster management does not stop the threats; instead it focuses on trying to decrease the impact of disasters. Disaster management includes activities that incorporate mitigation, preparedness response and recovery. The past decade has seen a significant increase in the use of social media for disaster management (Ngamassi et al., 2016; Denis et al., 2014; Hiltz et al., 2014; Hughes, 2014; Yates & Paquette, 2011). Several studies have identified a number of reasons for the use of social media for disaster management by humanitarian organizations and other stakeholders engaged in disaster relief. These reasons include (i) to seek information - information seeking is a primary driver of social media use during routine times and during disasters (Merrifield & Palenchar, 2012); (ii) to receive timely information – social media provides real-time disaster information, which no other media can provide (Kavanaugh et al., 2011; Spiro et al., 2012); (iii) to determine disaster magnitude – people use social media to stay apprised of the extent of a disaster (Liu et al., 2013; Sutton et al., 2008); (iv) to check in with family and friends (Gao et al., 2011; Semaan & Mark, 2012); and (v) to self-mobilize - During disasters, the public may use social media to organize emergency relief and ongoing assistance efforts from both near and afar (Gao et al., 2011; Starbird & Palen, 2011). With the recent development in social media, lack of data is no longer a major issue for disaster management. One key challenge, rather, is managing the information, translating it into actionable knowledge for effective decision making.

The past decade has also seen a growing interest in visual analytics as a new research field (Scholtz, 2006;

Thom, 2015). Visual analytics is defined as "the science of analytical reasoning facilitated by interactive visual interfaces" (Thomas and Cook, 2006). It can be seen as a set of techniques that use graphics to present information that helps users visually inspect and understand the results of underlying computational processes (Fan & Gordon, 2014). According to Wingkvist et al. (2011), visual analytics can be a useful way to address problems that are difficult to solve using either machine analysis or human analysis, for example due to size or complexity. Visual analytic tools are also on the rise. These tools support analytical reasoning using visual representations and interactions, with data representations and transformation capabilities, to support production, presentation, and dissemination (Scholtz, 2006; Gotz & Zhou, 2009). They also promise to supply analysts with the means necessary to tackle complex and dynamic problems and to support collaboration among analysts (Robinson, 2008). Visual analytic tools enable analysts to interactively explore and derive insights from large corpora of information by exploiting human visual perception and abstract reasoning (Gotz & Zhou, 2009). The combination of visualization, machine analysis and human expertise can prove helpful to reduce both size and complexity of problems (Wingkvist et al., 2011) similar to those inherent to disaster management.

Research in this area of social media visual analytics for disaster management however lacks a comprehensive overview. Hence, this paper presents a synthesis of extant research on social media visual analytic and visualization toolkits for disaster management. We survey available literature on these tools with the goal to outline the major characteristics and features, and examine the extent to which they cover the full cycle of disaster management. The rest of the paper is presented as follows. In the next section, we provide a theoretical background followed by a brief discussion of our research methodology. We then present our data and analyze our findings. This analysis is organized based on insights gained from previous similar studies (e.g. Dorasamy et al., 2013; Pohl, 2013). In closing, we suggest future research directions to enhance social media visual analytic tools for disaster management.

BACKGROUND INFORMATION

We present in this section, some background information for our paper. It includes a discussion on (i) a reference model for the process of disaster management and (ii) the features of social media analytic tools.

Reference Model for the Process of Disaster Management

The literature discusses a reference model for the process of disaster management based on the following phases: mitigation, preparedness, response, and recovery (Lettieri et al., 2009; FEMA, 2010).

The mitigation phase involves the actions aimed to minimize the degree of risk, to prevent disasters and to reduce the vulnerability of both the ecosystem and social system (Lettieri et al., 2009). The goal of the activities in this phase is to protect people and structure and reduce the cost of activities during the response and recovery phase (FEMA, 2010). The main functions of the mitigation phase include hazard assessment, vulnerability and risk reduction (Lettieri et al., 2009).

As it is almost impossible to mitigate all possible risks and casualties involved during a disaster, it is very important to have some preparedness measures that can lessen the impact of disaster (FEMA, 2010). Preparedness involves actions to prepare responders and common people to post-disaster activities (Lettieri et al., 2009). The strategies to be carried out during preparedness should be put in place before the disaster occurs. Planning for strategies in this phase involves ascertaining supplies and resources that may be essential in case of disaster, designating amenities for emergency use, and employing, assigning, and training personnel who can support in crucial areas during recovery and response operations (FEMA, 2010).

The response stage begins when a disaster is imminent or immediately after the disaster occurs (FEMA, 2010). Response consists of actions to manage and control the various effects of disaster and minimize human and property losses (Lettieri et al., 2009). Response also involves putting the strategies developed during the preparedness phase into action (FEMA, 2010). Further, in this phase, depending on the type of emergency, it is very important to prioritize the response activities and also deploy the resources that may be scarce. Irrespective of the type of disaster, the main functions of the response phase include evacuation, sheltering, medical care, search and rescue, property protection, and damage control (Lettieri et al., 2009).

The recovery phase aims at ensuring that the community activities and the systems return back to normal functioning. Recovery consists of those actions that bring the disrupted area back to an often improved normal condition (Lettieri et al., 2009). Recovery is unique to each community or area depending on the type of disaster, the extent to which the community is affected by the disaster and the resources that are available or can be procured by the community.

Social Media Analytic Tool Features

Social media analytics involve a variety of analytical approaches borrowed from different fields (Heer and Agrawala, 2006; 2008; Stieglitz and Dang-Xuan, 2013; Fan and Gordon, 2014). These approaches could be grouped into four broad categories including (i) topic/issue/trend-based approaches (ii) opinion/sentiment-based approaches, (iii) structural based approaches, and (iv) visualization/visual analytics. For each of these categories, we present the features that are most relevant in analyzing and presenting social media data as discussed in the literature.

Topic/issue/trend-based approaches

The most common features in this category include topic modeling and trend analysis. Topic modeling entails employing statistics and machine learning to detect main themes or topics in large body of text (Fan and Gordon, 2014). The themes or topics uncovered can be used to provide consistent labels to explore the text collection further or to build effective navigational interfaces. Trend analysis is used for identifying and predicting future outcomes and behaviors based on historical data collected over time. Trend analysis is based upon longstanding statistical techniques such as time-series analysis or regression analysis.

Opinion/sentiment-based approaches

Opinion mining and sentiment analysis are the main features in this category. Opinion mining is the core technique behind many social media monitoring applications (Fan and Gordon, 2014). It is used to measure the views, and beliefs based on the criteria that depend on the purpose of analysis. Sentiment analysis is used to measure the individual, group, communities' emotions towards an events (Wamba et al, 2016)

Structural based approaches

Social network analysis is the main feature in this category. Social network analysis is used to analyze a social network graph to understand its underlying structure, connections, and theoretical properties as well as to identify the relative importance of different nodes within the network (Fan and Gordon, 2014).

Visualization/visual analytics

Information visualization provides significant help to the human visual system to support the analysis of big data. There are several basic data types in information visualization (Shneiderman,1996 ; Tory and Moller, 2004). The most common identified in the literature include (i) graphs, (ii) trees, (iii) n-dimensional data, and (iv) geospatial and spatio-temporal visualizations. Graphs are any data that contains information that can be represented as nodes or vertices, and edges connecting these nodes (Harger and Crossno, 2012). Trees are a special class of graphs that have explicit hierarchical structure which allows them to be laid out in more ways than graphs in general (Harger and Crossno, 2012). N- dimensional data is a very general data type that includes all information that can be represented as the rows and columns of a table. This category includes bar charts, line charts, pie charts, stacked charts, box plots and views supporting multidimensional data. Geospatial and spatio-temporal category is useful for viewing geographic information.

Visual analytics can be regarded as a collection of techniques that use graphical interfaces for presenting summarized, heterogeneous information that helps users visually inspect and understand the results of underlying computational processes (Fan and Gordon, 2014). It involves a range of activities, from data collection to data-supported decision-making.. The primary goal of visual analytics is the analysis of vast amounts of data to identify and visually distill the most valuable and relevant information content (Keim et al, 2008).

METHODOLOGY

We conducted a review of the literature in which studies were included in three steps. First, we used the ABI INFORM and EBSCOHOST electronic databases as the main sources for identifying studies on social media for disaster management. Only peer-reviewed papers published in the last decade were considered for our study. We focused on three main research areas including (i) social media and (ii) disaster/crisis/emergency (iii) visual analytics/visualization. We included visualization in the research area because we found out that there were few visual analytic toolkits available. For the database search, we used different combinations of the following keywords "social media", "social media technology", ", "social media tools", ", "social media platform", "disaster management", "disaster management phases", "crisis management", "emergency management", "disaster relief", "visual analytics", and "information and communication technology". We considered only papers that had at least both "social media" and "disaster" , or "crisis" or "emergency" and "visual analytics" or "visualization" keywords. An initial screening of the titles and abstracts indicated that not all of the papers retrieved by the keyword searches were appropriate to the study. These papers were excluded from our sample.

Second, in addition to the journals listed in ABI INFORM and EBSCOHOST, we also selected papers from the International Journal of Information Systems for Crisis Response and Management (IJISCRAM), which provides an outlet for innovative research in Information Systems for crisis response and management. We also purposefully searched the conference proceedings of Information Systems for Crisis Response and Management Conference (ISCRAM) a renowned conference in IS. The ISCRAM community is a mix of researchers and practitioners dedicated to the promotion of exchange of knowledge and the deployment of IS for crisis management. ISCRAM has a track on social media in crisis response and management.

Third and finally, we used the ''snowball'' method to find additional relevant papers. The snowball method involved carefully going through the references of the papers identified in the two previous steps and look for additional papers suitable for our study. We present in **Table 1,** the list of the social media visual analytic tools resulting from our search. They are thirty one (31) in total. For each of the tools, we also provide the main reference and in some cases, additional related references.

TABLE 1: Social Media Visual Analytics Tools for Disaster Management

	Tools	**Main Reference**	**Other Related References**
1	AsonMaps	Aulov et al., 2014	
2	Coordinated Engagement Interface (CEI)	Purohit et al., 2014	
3	Crisees	Maxwell et al., 2012	
4	Disasters2.0	Camarero & Iglesias, 2009	
5	Emergency Response Intelligence Capability (ERIC)	Power et al., 2013	
6	Emergency Situation Awareness – Automated Web Text Mining (ESA-AWTM)	Yin et al., 2012b	Yin et al., 2012a; Cameron et al., 2012 ; Power et al., 2013
7	Global Disaster Alert and Coordination System (GDACS)	Stollberg & Groeve, 2012	
8	G-SAW	Croitoru et al., 2012	Crooks et al., 2013
9	Mapster	Liu et al., 2011	
10	Riskr	Farber et al., 2012	
11	Sahana	Careem et al., 2006	Duc et al., 2014; Sahana Software Foundation 2011
12	Scatterblog	Bosch et al., 2011	
13	SensePlace2	MacEachren et al., 2011	MacEachren, 2013; Savelyev and MacEachren, 2015
14	Social Media Analytics Reporting Toolkit (SMART)	Zhang et al., 2014	Zhang et al., 2016
15	SocialSensor	Diplaris et al., 2013	Papadopoulos et al., 2013
16	System for Real and Virtual Volunteers (SRVV)	Reuter et al., 2013	
17	Twitter Earthquake Detector (TED)	Guy et al., 2010	
18	TEDAS	Li et al., 2012	
19	Toretter	Sakaki et al., 2010	Sakaki et al., 2013
20	Tweak-the-Tweet	Starbird & Stamberger, 2010	Starbird, 2011
21	TweetComp1	Zielinskiet Al et al., 2013	
22	TweetTracker	Kumar et al., 2011	

23	TweetXplorer	Morstatter et al., 2013	
24	Twitcident	Abel et al., 2012a	Abel et al., 2012b; Tao et al., 2012 ; Terpstra et al., 2012
25	TwitInfo	Marcus et al., 2011	
26	Twitris+	Sheth et al., 2011	Purohit & Sheth, 2013
27	Ushahidi	Anahi 2011	Okolloh, 2009; Duc et al., 2014; Li et al., 2014
28	Visual Analytics of Microblog Data for Public Behavior Analysis in Disaster Events (VAMPBA)	Chae et al., 2013	Chae et al., 2012 ;Chae et al., 2014
29	Visual Backchannel	Dork et al., 2010	
30	WeKnowIt	Ireson, 2009	Cordis, 2009; Lanfranchi & Ireson, 2009; Lanfranchi et al., 2010
31	XHELP	Reuter et al., 2015	

REVIEW FINDINGS AND DISCUSSIONS

In this section, we present and discuss our review findings. We start with a brief general overview of the important characteristics of the thirty one (31) social media visual analytic toolkits identified in the literature. Then, based on a discussion on the social media activities specific to each phase of a full cycle disaster management, we suggest the features of visual analytic toolkits that we believe would be relevant for that phase.

Overview of the Toolkits Identified

Social media visual analytic toolkits differ in a number of ways. In this paper, we examined the following characteristics: maturity, platform, disaster specific, data source and key features provided.

Maturity

The thirty one (31) toolkits examined in this study have varying degrees of maturity, with a large majority still under development or at most under test. Few of them have been effectively used in real case of disaster management. For instance, findings from our examination of the toolkits suggest that only Sahana and Ushahidi have effectively been used for large scale disaster management. Sahana is an open source and open standards software developed with the aim to enable disaster responders to access and share information in order to reduce human suffering during pre-disaster preparedness and post-disaster response phase (Duc et al., 2014). Ushahidi is also an open source software. It was developed to help automate the collection of incident reports using cellular phones, email, and the web and facilitate the mapping of report locations in an interactive map mashup along with descriptive data to contextualize events. Ushahidi was first deployed in full scale for disaster management during the 2010 Haiti earthquake.

Platform

A large majority of the 31 toolkits examined are web based. The few that are multiplatform include GDACS, Mapster, Sahana and Ushahidi. For instance, Mapster is a mobile+Cloud system designed to provide a set of loosely coupled components, including (i) a citizen reporting tool on the smartphone through a customized Twitter client, (ii) Cloud-based semantic streaming data fetching, processing and republishing services, and (iii) a personalized/localized spatiotemporal visualization and animation tool on the phone that can visualize both citizen-provided data as well as infrastructure sensing data (Liu et al., 2011).

Disaster specific

Some of the toolkits are designed for a specific type of disaster. For example, Twitter Earthquake Detector (TED) and Toretter (Sakaki et al., 2010; 2013) are designed specifically for earthquake. TED is developed to mine real-time data from popular social networking and micro-blogging sites, searching for indicators of earthquake activity directly from the public (Guy et al., 2010). According to Guy et al. (2010), TED also integrates traditional scientific earthquake information, location and magnitude, from the USGS internal global earthquake data stream with geospatial-temporal corresponding citizen reports from popular social networking and micro-blogging sites. The TED system analyzes social networks data for multiple purposes including to (i) integrate citizen reports of earthquakes with corresponding scientific reports, (ii) infer the public level of interest in an earthquake for tailoring outputs disseminated via social network technologies, and (iii) explore the possibility of rapid detection of a probable earthquake, within seconds of its occurrence, helping to fill the gap between the earthquake origin time and the presence of quantitative scientific data (Guy et al., 2010). Based on particles filtering, Toretter analyzes the flow of twitter to detect earthquakes and alert users (Sakaki et al., 2010; 2013). Users can see the detection of past earthquakes (Sakaki et al., 2010; 2013). They can register their e-mails to receive notices of future earthquake detection reports. Toretter alerts users and urges them to prepare for the imminent earthquake (Sakaki et al., 2010; 2013).

Features provided

Most of the tools identified are developed around the concept of a dashboard, or a set of visual screens that provides a summary of social media during the crisis according to a variety of dimensions including temporal, spatial, and thematic aspects. Common elements in these screens include line charts, timelines, time series graphs, maps, pie charts, bar charts, stacked charts, box plots and views supporting multidimensional data (such as scatterplots and parallel coordinates) [See Table 3]. For instance, ScatterBlogs is a system that enables users to interact with the data in a visual, direct, and scalable fashion (Bosch et al., 2011; Thom et al., 2013). Its main objective is to allow analysts to work on quantitative as well as qualitative findings by (i) automatically identifying anomalies, (ii) summarizing and labeling event candidates, and (iii) providing interaction mechanisms to examine event candidates (Thom et al., 2013). ScatterBlogs also provides a workbench allowing the scalable visual examination and analysis of messages featuring perspective and semantic layers on a world map representation (Bosch et al., 2011; Thom et al., 2013). Another example is SensePlace2, a map based interactive application. , SensePlace2 includes features that allow the users to (i) explore and analyze data, (ii) visualize data on a map and as word clouds, and (iii) select time interval and terms of interest (MacEachren et al., 2011). SensePlace2 uses Twitter as the main source of geospatial information. Although some of tools are based on input or feedback provided by emergency responders and other officials (e.g. Ushahidi), we found that the majority are designed as a way to process social media data during crisis situations.

Table 2: Tools Features

	Tools	**Features**							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1	AsonMaps	√							
2	CEI			√					
3	Crisees	√			√		√		
4	Disasters2.0	√							
5	ERIC	√							
6	ESA-AWTM	√			√	√			√
7	GDACS	√						√	
8	G-SAW			√	√	√	√		
9	Mapster	√			√				
10	Riskr	√		√	√				
11	Sahana	√		√	√				
12	Scatterblog	√			√	√			√
13	SensePlace2	√			√	√			
14	Smart	√							
15	SocialSensor	√	√		√	√	√		
16	SRVV	√		√					
17	TED	√		√	√			√	
18	TEDAS	√			√				√
19	Toretter	√		√	√				
20	Tweak-the-Tweet	√			√	√			
21	TweetComp1	√			√				

22	TweetTracker	√			√				
23	TweetXplorer	√		√	√				
24	Twitcident	√			√			√	
25	TwitInfo	√			√	√			
26	Twitris+	√			√			√	
27	Ushahidi	√	√	√	√	√		√	
28	VAMPBA	√	√				√		√
29	Visual Backchannel	√							
30	WeKnowIt	√			√	√			
31	XHELP	√							

A	Topic/Issue/Trend analysis	E	Timeline (visualization option)
B	Opinion/Sentiment analysis	F	List (visualization option)
C	Social network analysis	G	Statistic Diagram (visualization option)
D	Map (visualization option)	H	Tag Cloud (visualization option)

Data source

The most common social media data source is Twitter. Other data sources include Facebook, Flickr, Instagram, YouTube, Tumblr and SMS.

Relevant Toolkits Features for Full Cycle Disaster Management

As discussed earlier, the full cycle of disaster management is made up of four phases. Each of these different phases has its own information requirements that need to be addressed. We suggest in this section the features of visual analytic toolkits that we believe would be relevant for each of the phases.

Mitigation:

In the mitigation phase, communication between organizations and other stakeholders engaged in disaster management primarily focuses on sharing and disseminating information about possible disaster treats; establishing rules and planning for resources to use in case of disaster (Fischer et al., 2016). A number of social media activities are undertaken to alleviate the harm that may occur from disasters. These activities may include creating and strengthening communication and collaboration networks, disseminating the do's and don'ts in case of disaster, drawing lessons learned from passed disasters etc. The appropriate features for visual analytic toolkits relevant for the mitigation phase of disaster management would include social network analysis, data management and information visualization.

Preparedness:

In the preparedness phase, organizations and other disaster managers work together to develop the processes that could help to effectively manage post-crisis (Fischer et al., 2016). They also need to be aware of communication challenges that may hinder these efforts. Moreover, it is important that disaster responders communicate to keep in touch, plan together for a crisis, and develop trust between organizations (Allen et al., 2014; Fischer et al., 2016). Furthermore, building relationships between all crisis responders through training and timely communication among organizations about plans and actions is critical for good collaboration during a crisis response (Fischer et al., 2016). Social media activities can be undertaken before a disaster strikes to improve the readiness of the community to respond quickly as soon as the disaster strikes; to engage citizens and to share preparedness information from humanitarian organizations. For example disaster related social media online training can be developed and offered to prepare disaster responders. Social media can be used to provide early warning when situations become less predictable and can also be useful in pointing out abnormal event (Fan et al., 2014). Houston et al. (2015) argue that prior to disaster, social media can be used in three different ways including (i) providing and receiving disaster preparedness information, (ii) providing and receiving disaster warnings, and (iii) detecting and signaling disasters.

Features for visual analytic toolkits relevant for the preparedness phase of disaster management would include topic modeling, trend analysis, social network analysis, data management, information visualization and visual analytics. Topic modeling, trend analysis of tweet data could be instrumental in this phase as they could help determine abnormal event and then provide early warning. For instance, several studies show that Twitter constitute a viable early warning system in disaster management (Chatfield and Brajawidagda, 2013; Tyshchuk et al., 2012). Studies also show that crisis response organizations use social media to provide advice directly for crisis preparation, point to other resources with crisis advice, and offer news about the crisis to the community (Van Gorp et al., 2015). To this end, features such as data management, information visualization would be necessary. Social network analysis would be necessary for a collaboratively developed knowledge base with active discussion spaces conducted normally during the preparedness phase of disaster management. In addition, citizens could use social media to share their emergency plans and to coordinate "ride shares" over their network for when there is a need to leave the area at risk (Belblidia, 2010). Moreover, using social media prior to disasters would enable emergency management networks to be built that share the responsibility for preparing for a disaster (Dufty, 2012).

Response:

The response phase of disaster management involves high degree of communication within and between the different organizations and other stakeholders engaged in disaster response (Fischer et al., 2016). Communication in crisis response includes adapting to the situation as quickly as possible, assessing the appropriateness of formal plans, and gathering and processing information for crisis professionals' decision making (Fischer et al., 2016). Social media tools are increasingly used as an information source for disaster response organizations. In responding to disasters (e.g. the 2010 Haiti earthquake, the 2012 Sandy superstorm), social media was used for relaying information, one and two-way communication, offering/requesting assistance and organizing disaster response (Watson and Wadhwa, 2014). Social media can also be used in the search and rescue operations during a disaster. For instance, the pervasiveness of smartphones gives people the opportunity to take photos or videos and upload them to the Web immediately. Survivors in an affected area can report what they are seeing or hearing.

Moreover, social media can also be used to monitor and analyze data generated during disaster in order to enhance situational awareness and the response to the disaster. The need to provide a fast and effective response to disaster victims means that the social media toolkits used for disaster response need to be able to quickly access and analyze a vast quantity of real-time social media data. Furthermore, compared to the disaster preparedness phase, vast amounts of data are generated during the response to disasters. Therefore, for disaster response social media visual analytic toolkits are required to have access to a large body of real-time data through agreements with social media applications such as Twitter.

Recovery:

Research has highlighted the importance of information sharing between organizations during the recovery phase of disaster management to coordinate activities and address tasks such as coordination, rebuilding, as well as dissemination of information about accessing aid (Cumbie and Sankar, 2012; Fischer et al., 2016). In this phase, organizations and other stakeholders engaged in disaster management use social media to publicize information about successful recovery activities, collect lessons learned that can help an organization better prepare for another crisis, and facilitate coordination and collaboration (Fischer et al., 2016). Further, organizations use social media to build relationships with the public and share information and coordination of volunteer activities (Fischer et al., 2016). The appropriate features for visual analytic toolkits relevant for the mitigation phase of disaster management would include social network analysis, data management and information visualization.

Suggested Features per Disaster Management Phase

	Mitigation	Preparedness	Response	Recovery
Topic modeling		√	√	
Trend analysis		√	√	√
Opinion mining			√	√
sentiment analysis			√	
Social network analysis	√	√	√	√
Data management	√	√	√	√
Visualization	√	√	√	√
Visual analytics		√	√	√

CONCLUSION

Research shows that social media is being increasingly used for disaster management. The use of social media visual analytics is also on the rise in disaster management. Social media visual analytics brings a new dimension to disaster management, offering a useful way to address problems that are difficult to solve using either machine analysis or human analysis with the possibility of potentially improving disaster management outcomes. In this paper, we present an overview of research on social media visual analytic and visualization toolkits for disaster management. The goal is to outline the major characteristics and features, and to examine the extent to which these toolkits cover the full cycle of disaster management. Our hope is that the overview presented here can contribute to provide a foundation based on the current literature and help to shape future research directions to enhance social media visual analytic tools for full cycle disaster management. For example, visual analytic tools could be developed to help determining the progress of an emergency (e.g. the rising level of flooding during a tornado or heavy rain) and to help identifying the next possible solutions (e.g. evacuation route) that could be used to alleviate the damages. Visual analytics tools could also be developed to determine the scope of damage and to provide various disaster responders with effective coordination tools for more efficient disaster response.

ACKNOWLEDGMENTS

This article was developed under an appointment to the DHS Summer Research Team Program for Minority Serving Institutions, administered for the U.S. Department of Homeland Security (DHS) by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between DHS and the U.S. Department of Energy (DOE). ORISE is managed by Oak Ridge Associated Universities (ORAU) under DOE contract number DE-AC05-06OR23100. This document has not been formally reviewed by DHS. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessary representing the official policies, either expressed or implied, of DHS, DOE, or ORAU/ORISE. DHS, DOE and ORAU/ORISE do not endorse any products or commercial services mentioned in this publication.

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Learning From Non-Acceptance: Design Dimensions for User Acceptance of E-Triage Systems

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ABSTRACT

As of 26 December 2016, seventeen electronic triage systems for disaster triage have been proposed in the ACM, IEEE, and ISCRAM publication databases. Most of these systems have remained inside the laboratory; the rest have disappeared entirely. Responders still prefer to do triage with paper tags from the 1960's, while no research has been presented on why the proposed e-triage systems have not found acceptance and use in the field. Based on exhaustive literature research and on the findings from the four-year long, EU research project BRIDGE , this paper presents e-triage acceptance dimensions, analyzes the main reasons why proposed systems have been rejected, and guides designers towards upcoming, well-accepted e-triage systems.

Keywords

Triage, E-Triage, Survey on existing approaches, Acceptance of ICT, Design guidelines

INTRODUCTION

Triage is the process of deciding which victims should be treated first in an emergency or disaster, given that there are not enough resources to treat all at the same time (WHO 2008). For the purpose of this research, a concise, generalised summary of triage is presented below. More detailed descriptions can be found in the works cited in the "State of the Art" section.

Seen separately from other, parallel-running response activities, triage consists of the following steps:

1. Estimate the victim's injuries and measure his or her vital values. This is usually carried out by direct inspection.
2. Mentally run a categorisation algorithm to determine priority of treatment. The input consists of the measured vital values, the output is a triage priority category. This priority gets further adjusted by the triager, depending on various, possibly ad-hoc, considerations.
3. Label the victim with a visible marker signifying the priority category. This helps other responders a) recognize that the victim has been triaged and b) recognize the victim's priority from afar. Any visible marker with an agreed-upon meaning may be used, but colored paper tags, clips, or plastic bracelets are the most common (Brownlee 2014).
4. Trigger the further handling of that victim. This usually means reporting the victim to the command post or to the treatment and transportation unit.

The measurement, categorisation, and marking must be completed within 15-45 seconds, depending on the legal framework (Wingerter 2013). There is no time to report each victim separately, so reporting is done after several or all victims have been triaged. This may delay transportation up to 20 minutes and medical treatment by 30-40 minutes (Donner et al. 2012; The BRIDGE Project 2011) .

The tools currently used for triage present various problems and limitations: the tags may be lost or damaged, information is handwritten, smeared, and unreadable, it takes too long for the data to reach the appropriate responders, location data is not captured, the needs of several responder groups are not fulfilled, etc. Such problems are extensively described in the research from the "State of the Art" section. This paper instead aims to critically analyse the proposed, IT-supported *solutions* to these problems, and to uncover why those solutions have not been accepted by first responders. After a categorized overview of proposed e-triage systems, the paper describes the methodology for assessing them. The subsequent section presents a set of e-triage acceptance dimensions, which influence whether responders adopt a proposed system. These dimensions are then used as basis for reviewing state of the art systems and approaches, so that it becomes clear why they have not been accepted in the field. Examples of typical problems are also provided for system designers to avoid design traps.

STATE OF THE ART ON ELECTRONIC TRIAGE SYSTEMS

A full-text search of "triage" in the ACM, IEEE, and ISCRAM publication databases shows 111 papers related to emergency and disaster triage[1]. 35 papers use IT to tackle singular problems. 39 papers present algorithms and systems for diagnostics, patient management, and hospital triage. 24 papers present 17 disaster e-triage systems (presented below in detail). Six papers mention triage as an example only. Five papers analyse the suitability of certain technologies for triage. Only two papers (of which one by this author) offer suggestions on how IT may impact the triage process itself. No papers analyse why electronic triage systems may fail.

The 17 e-triage systems proposed so far are listed below, grouped by common technology and interaction style.

WIMP or Touch-based mobile interfaces

Responders interact with these systems through a GUI on a mobile device they carry. The triage marker tag itself may or may not have computing capabilities.

Infrastructure-dependent systems

These systems require special infrastructures to exist or be created before triage can start.

WIISARD (Killeen et al. 2006) requires a WiFi mesh network to be deployed on the field before triage can start; this deployment, according to (Chipara et al. 2012), takes one hour or more. Triage tags are still made of paper, but they have a barcode that connects the tag to data entered on a PDA. By the authors' own testing, triage took on average 40 seconds per victim, with a range of up to 4 minutes.

The CrowdHelp system (Besaleva and Weaver 2013a; Besaleva and Weaver 2013b; Besaleva and Weaver 2013c) consists of a smartphone app for victims and a server-side backend for responders. After victims submit their symptoms, injury locations, and other relevant information through the app, they get informed about their possible diagnosis and what to do next. The triage category is assigned automatically, based on the self-reported symptoms. Machine-learning software offers responders a number of filters and visualizations, among which a clustering of the victims according to position and severity. The clusters are colored with the median triage category of the respective victims.

(Chandra-Sekaran et al. 2008) proposed a "Disaster Aid Network" composed of PDAs for the responders to monitor and record data, and ZigBee tags with temperature sensors for the victims. The system uses signal strength and temperature to calculate the victims' locations and the hot, warm, and cold zones respectively[2]. The authors report that calculation takes about 8 minutes and that localization reaches up to 2 meters accuracy, but that it needs a large number of position reference stations to be installed.

(Adler et al. 2011) present a concept based on handheld devices, satellite communications, and distributed databases. A tablet with special software is used for data input; network base stations need to be installed for connectivity. There is no automatic triaging. The system is intended for daily use as well as in disasters, but its interface differs between the two modes.

[1] These databases were chosen as the largest research collections on computing and electronics. We also consulted the "related work" cited by those papers that propose an e-triage system and we used general-purpose search engines as well, but the results lead back to the same databases.

[2] The hot, warm, and cold zones in a disaster area refer respectively to the dangerous, relatively dangerous, and safe areas.

Infrastructure-free systems with data-free triage tags

These systems do not require special communications infrastructure, but the tags they use typically serve only as an index into some database. No data is saved on the tag.

(Martín-Campillo et al. 2010; Martín-Campillo et al. 2011) proposed using a GPS/RFID-enabled smartphone and RFID chips embedded in paper tags. The triager must scan the RFID chip, use a GUI to run through the triage algorithm, and finally put the paper tag on the victim. The data are forwarded to the command post via opportunistic Wi-Fi links between the smartphones. Since each triager is supposed to return to base by a certain time, the data is selectively forwarded to the smartphone of the triager with the least time left before returning.

(Chang 2011) proposed an e-triage system with colored, active RFID tags, which can be read from a distance. Data is entered and saved in a PDA, then transmited over a Wifi or Cellular network to a central server and to the hospitals that will treat the victims. No data is saved on the tags. Colored LEDs show the triage category of the victim, with three blinking LED's showing a deceased victim.

(Raytheon 2007) presented an emergency patient tracking system based on barcodes, PDAs and WiFi communications. The data reside in a central, web-enabled database and are accessible to the command center, hospitals, and other agencies. The system was meant to be offered commercially, but as of 2016 its only remaining trace is the cited press release.

Infrastructure-free systems with data-containing triage tags

These systems also don't need special communications infrastructure, but the tags they use have sensing and/or computing capabilities and can communicate independently of the triager's handheld device.

AID-N (Gao et al. 2007) presented electronic tags with non-invasive sensors for continuous monitoring of victims' vital values. Triagers set the priority by inserting a specific card into the tag; an LED lights up to display the assigned color. Data is transmitted via a ZigBee network among the tags to gateway computers and from there to a central server. Data input is done through a PDA, while medics at the holding area can monitor multiple victims at once on a WIMP GUI. The system offers automatic monitoring of victims.

WIISARD v2 (Chipara et al. 2012) presented a fundamentally new communication architecture based on a ZigBee mesh network, "gossip"-protocols, and message broadcasting. The interaction with the system remained the same as WIISARD v1, i.e. PDAs were used. For cases when responders have to wear protective suits and can't use PDAs, a hardware tag with an RFID chip, display, and input buttons was provided (Lenert et al. 2011). Realistic testing of WIISARD showed an improved amount and quality of patient documentation, but the authors could not exclude a Hawthorne-effect (Lenert et al. 2011). Average triage time remained the same as with paper tags; it even increased for the "immediate" priority victims (i.e. the critically injured).

(Gillis et al. 2015) proposed a system based on Google Glass, while (Rocío Fuentes Fernández et al. 2014) used the Glass similarly, but with a voice-driven interface, since responders' hands are often busy. The triage category is determined automatically by asking questions about the victim to the triager. Even so, a third of the tested users (2 out of 6) told the app the triage category directly instead of answering the questions. (Berndt et al. 2015) report that head-mounted displays are suboptimal for emergency applications.

CodeBlue, a software infrastructure for sensor networks (Lorincz et al. 2004), used triage as a testbed application, similar to the above-mentioned PDA + WIMP GUI approaches. The authors took into account how the CodeBlue infrastructure could impact usability and designed the system accordingly. For example, they offer "best-effort" instead of "strong" security, since the necessary logins and PKI for strong security are incompatible with field work. Whereas CodeBlue was only a testbed, its architecture was reused in several of the e-triage systems listed here.

The triage device first proposed by (Sakanushi et al. 2011) (see "Dedicated Hardware Interfaces" below) was used by (Takahashi et al. 2011) for secondary triage (re-triage, the re-classification of the priority at the holding area, based on changes to the victim's vital values). The authors propose a touch-screen UI where a doctor can choose or draw the injury location and type. Together with sensor values, this input is used to automatically re-triage the victim. The authors report very positive evaluation results, but the system was only tested with students, in a tabletop exercise, and with victim information read from printed notes.

(Lawatschek et al. 2012) present ALARM, an emergency management system that also supports triage. Data are mirrored not only on an ad-hoc Wi-Fi network, but also on a passive, programmable RFID tag on the victim. A GPRS/UMTS/Satellite gateway makes the data available remotely. To provide visibility of triage status, the triager must stick colored labels on the tags after programming them. The system offers different devices to different roles, depending on their context: glove-tolerant smartphones for triagers, tablets for treatment area medics. Process efficiency measures are also taken and movements are logged.

A similar approach was undertaken in DIORAMA by (Ganz et al. 2013); triagers need to apply both an RFID tag *and* a paper tag to victims. Victim positions are shown overlaid on the commander's map. Active RFID tags are used to support RFID-based positioning. The tags transmit over Wi-Fi and the responder's helmet has a Wi-Fi receiver. To discern which tag is being manipulated, the tag should touch the reader device and a button should be pressed simultaneously. The system logs all information and can replay every movement on the scene.

Dedicated Hardware Interfaces

The triage interface in these devices is on the tag itself. The tag has, of necessity, computing capabilities. All the systems proposed so far that fall under this category also happen to be infrastructure-free.

(Sakanushi et al. 2011) proposed an electronic tag based on a blood oxygenation and pulse sensor. The tag is attached by inserting a finger from the victim in the appropriate sensor opening. The interface consists of eight LED-s to signal questions for the triager, and two buttons labeled "Yes" and "No" to input the answers. The system triages the victim automatically. Data are transmitted to a central server via a ZigBee network. The authors report halving the time it takes to triage a victim and lowering the death rate from 22.4% to 14%, but these are theoretical results, not empirical measurements.

(Carella and McGrath 2006) focused specifically on the military's requirements and proposed ARTEMIS, an e-triage system using embedded sensors to decide the triage category automatically. Data is transmitted via ad-hoc WiFi networking and a publish/subscribe middleware concept. The triage tags and monitoring sensors continue sending data all the way to the hospital, which provides continuous monitoring of the victim and a log of the data from the beginning.

(Noe 2010) used ZigBee sensors and microcontrollers to design the hardware for an electronic tag. Particular attention was paid to energy efficiency, scalability, and resiliency of the systems. The author's evaluation was focused not so much on actual use and acceptance as it was on the raw technical performance of the system, which was shown to handle hundreds of tagged victims at once.

Partial approaches to electronic triage

Various other papers and technology studies tackle only one aspect of e-triage, such as network routing, or only the suitability of certain IT technologies for e-triage. This research is listed here for completeness only, since it does not present a usable triage system.

(Kobayashi et al. 2010) propose a way to discover a walkable path from a doctor's location to a victim that needs attention.

(George et al. 2010) proposed DistressNet, an architecture for wireless networks made up of sensor nodes organized in a certain hierarchy. The proposed composition and protocols have since been superseded, but the basic architecture was used in several of the other e-triage systems.

(Lubrin et al. 2006) used the UTAUT model to judge the acceptance of sensor motes in medical institutions. The authors conclude that sensor motes are generally unknown to people, they present problems in how much effort they demand, they negatively affect privacy, and as a result they may not be well-accepted in a medical context.

(Garson and Adams 2008) tackle security and privacy in a hospital emergency context. They recognize that certain security solutions are incompatible with emergency work and propose ways to build usable security architectures for emergency situations.

(Togt et al. 2004) studied the added value from location-based services in disaster response. They also analyzed the types of information needed and found out that positioning and LBS need to be available indoors, not just outdoors.

Design frameworks for e-triage systems

(Turoff et al. 2004) proposed the DERMIS design model to generate a Management Information System for Emergency Response. While the outlined principles are sound, they are necessarily generic, driven by an MIS focus, and are not tailored to electronic triage. Some design principles for e-triage were also proposed by (Gao et al. 2007), but, as the authors themselves note, they are focused on re-triage and on the medics at a treatment area rather than on the complete triage process and on responders in general.

RESEARCH METHODOLOGY

This paper is based on research carried out over four years in seven countries as part of the BRIDGE project[3], an EU-funded FP7 research whose goal is to develop technical and organisational solutions for inter-agency, cross-border crisis and emergency management. An e-triage system was developed through a combination of participant-centered design, participatory design, and grounded theory methods (Slavin 2016; Greenbaum 1991; Glaser and Strauss 1967) as described in following. The research and development for this system led to the recognition of both the needs of first responders and their problems with the e-triage approaches proposed so far.

User Centered Design (UCD), (Norman and Draper 1986), which focuses on end users and their context to build fitting systems, has traditionally been recommended for designing emergency-related systems (South West Thames Regional Health Authority 1993). In the course of this research, however, a purely *user*-centered approach showed weaknesses. Triage is essentially an interaction between two responders, where one responder's understanding of the situation is transmitted to another responder, at a different place and time; an e-triage system is a machine that *mediates* this *human-human* interaction. UCD, in comparison, was meant for human-machine interaction. A second problem with UCD arises through its focus on "users". Few responders "use" a triage system directly (triagers, holding area medics), but the system impacts the work of many others (incident command, victims themselves, ambulance medics, doctors in a hospital, logistics managers[4], etc.). A participant-centered approach, focused on all the response participants impacted by triage, proved to be a better approach (Slavin 2016).

To take advantage of expert knowledge and to assure the acceptance of the final system among responders, participatory design techniques were used (Greenbaum 1991; Ehn 2008). An Advisory Board of responders worked with us to design the system and create prototypes. Testing and validation was carried out with other responders in multiple realistic emergency exercises with 20-400 participants.

Finally, as the resulting e-triage system was willingly accepted and successfully used by responders, with no training necessary, we used a grounded theory approach (Glaser and Strauss 1967) to understand its success factors[5]. A grounded theory approach was made necessary by the lack of acceptance models for e-triage systems in particular, and scarcity of models for emergency systems in general. The existing acceptance models (Turoff et al. 2004; Venkatesh et al. 2003; Dishaw et al. 2002; Ammenwerth et al. 2006; Goodhue and Thompson 1995) link an individual's past experience with IT to their present attitude towards IT and to their future decision to use IT for a given task. These are unfortunately too generic for the restricted, niche context of e-triage. Only (Turoff et al. 2004) takes into account some trade-offs of disaster management and offers some emergency-domain factors that impact experience. None of the models offer actionable advice on how to design an e-triage system for acceptance.

The empirical research for this paper involved firefighters, paramedics, doctors, police, disaster relief workers, logistics support managers, incident commanders, and hospital doctors from Norway, UK, Netherlands, Ireland, Switzerland, Austria, and Germany. At least two different methods of investigation were used for each question to reveal latent and tacit needs, as recommended by (Sanders 1992). As part of the user research, several e-triage systems from the state of the art were discussed with end users. Table 2 in the Appendix presents the detailed research activities. More than 300 hours of user research work and 30 hours of user testing with our prototype implementation were carried out with emergency responders and other domain experts, under realistic conditions, and in large-scale exercises:

- A train accident and a mass car crash in a tunnel in Switzerland, both accompanied by fire. Three Swiss and one Irish fire brigades were involved, each with 20-30 members, as well as paramedic teams.
- A chemical accident accompanied by flood and heavy weather in a populated area in Germany. Paramedics, Army, Police, and Logistics were involved.
- A terrorist attack at a petrol terminal port in Norway. 400 national responders were involved: firefighters, medics, triagers, and police.

The events' distribution supports the international applicability of the findings such that results are not bound to national regulations.

[3] http://www.bridgeproject.eu/en

[4] As an example, logistics support organizations do not do triage, yet they have to provide the infrastructure, power, and other technical resources needed by it.

[5] Responder organisations expressed interest in purchasing the developed system as soon as the development work finishes.

STAKEHOLDER NEEDS TOWARDS A TRIAGE SYSTEM

When analysing why an e-triage solution succeeds or fails with responders, it is necessary to know what responders deem an improvement over the current, paper-based triage and what do they wish an e-triage system could do. Two key observations are in order here:

- Throughout the rest of this paper, the term "responders" is preferred instead of "triagers", because a triage system touches upon many responder groups (see section "Research Methodology").
- Even though the same responder may perform multiple roles (e.g firefighting and triage), these roles never overlap in time. Each responder performs only one role at any given moment. The separation of roles is so strong that a) the role must be considered as a separate, orthogonal dimension when describing users and groups, and b) user needs can best be summarised by role instead of by other dimensions like demographics, task experience, or attitude to IT. This is how user needs have been grouped and presented below.

Triagers need a fast and reliable way to mark the victim's category and to leave notes for other responders who handle each victim. The triage tools should continue to be extremely lightweight. A way of knowing where there might be other, not-yet triaged victims, is also desirable. The system should grant triagers ultimate authority in what priority a victim gets, and should avoid the possibility for triagers to be penalized for their good-faith actions and decisions.

Victims need a system that does not cause them pain or further injury (e.g. by requiring them to move or expose skin for sensor contact). They also need the system to assure fairness, i.e. not allow low-priority victims to steal triage tags from high-priority ones[6].

Firefighters need the triage system to not cause them any more work than they already have to do. If they must do something related to triage, then a) they would accept to put a mark or label on the victims b) the tools for marking should be extremely lightweight, fast, easy to use, and reliable, c) the mark must not be interpreted as a triage priority (Elmasllari 2017) .

Paramedics need the system to tell them ASAP where triaged victims are and what is their priority[7]. If the triager has left notes related to the victim, the paramedics should be able to access those notes. An improved triage system should also help paramedics detect which victims have exchanged their markers.

Treatment area (TA) medics need the system to allow easy re-triage, both to a lower and to a higher priority. Since many medics are also triagers, re-triage should be done using the same tools as primary triage, in order to avoid confusion. Also, in order to fulfill the hospital doctors' need for a history of the victim's vital values, the TA medics want the system to help them monitor the victims, make notes, and log vital values (Elmasllari 2017) . Ideally, the system would also raise an alarm when these values change so much that a re-triage is warranted.

Incident commanders need to know how many victims there are from each category and how are they spread on the incident area. They need this information ASAP.

Hospital doctors need the victims to be transported to hospital as soon as possible, which requires triage to not be a bottleneck and quickly allow victims to be transported. The doctors also need a detailed history of the vital values as well as the notes about each victim.

The hospital administration needs the victim's generalia; if possible these should come automatically into the hospital's systems. The same generalia are also of interest for the **police** in order to investigate or notify families.

During the disaster, **response organisations** need to know at what point in the workflow each triaged victim is. They want a system that does not require workflow or organisational changes; ideally no training is necessary to use it, because such training is expensive and must be repeated often. The system should also be usable in daily emergencies (heart attacks, car crashes etc.) so that the doctors and paramedics who do triage have a fresh memory of how to use it (Elmasllari 2017; *The BRIDGE Project*) . Triage tools should allow responders to override them, use them in unforeseen ways, replace them ad-hoc, or combine them with other tools and systems, all without losing the capability to perform triage. The system should also allow to analyse and learn from past response interventions.

Logistics support organisations need the triage system to be cheap and ready at a moment's notice and be low- or no-maintenance. It should not require particular infrastructures, especially power or communication. Ideally, the triage system's components should be in a single grab-and-go bag, ready to use.

[6]It has happened that low-priority victims steal a high-priority tag from an unconscious victim (*The BRIDGE Project*) .

[7]It is not necessary to know where a particular victim is, as a victim's personal characteristics do not play a role in getting that victim out before other victims of the same priority.

For all roles the system should be usable in all kinds of weather and incidents (including chemical/radioactive, underground or in altitude, etc.), be usable even in a degraded state (Elmasllari 2017) , and should not increase the risk to responders (e.g. the system should not create sparks or intense radiation). Also, since "It is impossible to predict who will undertake what role in a crisis situation." (Turoff et al. 2004), no aspect of the system should depend on knowing the users' roles and intentions in advance.

LESSONS LEARNED FOR E-TRIAGE SYSTEM DESIGN

E-triage acceptance dimensions

By categorising the findings from our user research, six e-triage acceptance dimensions were identified to have impact on the adoption of a system. For each acceptance dimension, typical problems and examples are presented. We have not yet identified the order of importance for the dimensions, but this remains an open topic for future work.

Dimension 1: Completeness and appropriateness for triage

An e-triage system is inappropriate for triage when, due to the system's design or features, it is not possible to complete triage correctly, or when it is only possible to do so with disproportionate effort and/or discomfort. The system is incomplete when it only supports a part of the triage-related processes, or only a part of the users. Inappropriateness for triage may signify incomplete understanding of the emergency response context.

Typical problems and examples include:

- Basing the triage decision on incomplete or unreliable data about the victim, for example when victims self-report their status and symptoms. Victims cannot be expected to correctly judge and honestly report their own symptoms. Victims who can coherently communicate are also not the ones that need immediate treatment.
- Forcing either a certain triage algorithm, or automated triage. Algorithms change in two occasions: at committee meetings, and during the disaster response. The former can be programmed, but the latter are decided on the spot and depend on the victim (a crime witness may get priority treatment), on the available resources (with no available beds, an immediate-priority victim may be tagged as "intermediate"), and on other socially-acceptable but legally-dubious criteria (children may be given higher priorities than the elderly). Systems that do not give the triager control over the triage decision will be deemed inappropriate for triage.
- Requiring too much information, inputs, or other work. Triage relies on two information elements: the presence of a triage tag, and its color (priority). Systems that require triagers to fill in victim details, connect sensors, etc. may hinder triagers for the benefit of other responders (see also Dimension 2 below).
- Not supporting improvisation and "mixing and matching" of triage tools and markers. When triage tags are in short supply or unavailable, triagers are trained to use anything colored as a triage tag: clothespins, spray paint, colored rope, etc. Restricting them the ability to use the e-triage system alongside such ad-hoc solutions will put the e-triage system at a disadvantage.
- Not providing for reliability and *useful* degradation to a *well-known, minimum-functioning state*. This is related to the above-mentioned mixing and matching. Responders expect their tools to be very robust and reliable, but they also know how exactly the tool may fail and what a failed tool can still be used for. An e-triage system that is not reliable, fails too often, or fails to a "black box" or "useless" state does not offer the kind of "useful degradation" that responders expect of their tools.
- Not keeping in mind the physical context. Triagers go into a disaster field with a pack of triage tags (36 in our case), carry up to 20 kg of personal protection, gloves, and tools, and walk over unstable, slippery ground. A 100 gram tag translates to an undesired 3.6 extra kilograms of weight at the very least.

Dimension 2: Impact on workflows

Disaster response is a highly choreographed effort that is undertaken in an unfamiliar, ever-changing, overloaded, and chaotic situation. Response workflows and processes are patterns of behavior that have proven successful time and again over decades, maybe centuries. Changing them introduces inefficiencies at two levels:

1. Since their conscious mind is overloaded, responders can do their job only if their behavior is an automated "skill" independent of conscious thought (Rasmussen 1983). Process and workflow changes make behavior knowledge-driven, which resides at the inefficient, slow, and error-prone conscious level of processing.

2. Most new requirements to the e-triage system come not from triagers, but from responders with less time-sensitive requirements. Changing the triage workflow may introduce inefficiencies into this time-critical step, for the benefit of less time-sensitive tasks.

Typical problems and examples include:

- Haphazardly mixing marking and monitoring aspects of the system into the same tool, artefact, or process. It is crucial to understand that triage does *not* include the "further handling" of the victim (transportation, monitoring, medical treatment, etc.). Triage is a marking process where the mark represents a) the victim's state at one point in time (Jentsch et al. 2013), b) the belief that this victim is saveable. Monitoring is instead a continuous or periodic observation *after* it has been decided that the victim is saveable. "At the end of the day, [triagers] need a very simple tool that says that a patient is a priority." (Brownlee 2014). Triagers need the system to optimally support marking. It is the other responders that need monitoring.[8]
- Redistributing or assigning new tasks to a role without a comparable benefit to that role. As an example: if the system requires triagers to enter vital values into a GUI, it forces a time-consuming workflow change without direct benefits to triagers: they still have to measure those values. But if the system requires triagers to clip wireless sensors on the victim, the additional effort might be justified by the time savings, since the triager could use the sensor values and would not need to measure them.
- Requiring responders to attend to IT instead of doing response. Typical examples are setting up IT and network infrastructure, configuring PDA and terminal network settings, and even inputting a username and password "for security reasons". In the words of a triager: "If you communicate on the radio [during triage], you're not caring about the victim." (*The BRIDGE Project*) . By the same token, if you are attending to IT, you are not caring about the victim either.

Dimension 3: Consideration for organisational needs

E-triage systems are used by individual users, but are provided, purchased, and maintained by response *organisations*. Failing to account for organisational needs and workflows is a common barrier to acceptance of e-triage systems. In the words of a response organisation manager:

> They come to us and offer us [emergency management systems]. Then we say "Great! How do we power them where the power lines have been destroyed?" They answer: "No problem, here's a generator." And we ask "OK, now where do we find the petrol for the generator when no oil truck can reach us over the piles of rubble on the road?" And then they go away. (Source: Personal interview)

Typical problems and examples include:

- The logistics of deploying the system are impossible to satisfy, or take too much time and effort. This is the case where the e-triage system needs some kind of power or communication infrastructure to be laid out before it can be used for triage.
- System maintenance is required, needs special training, is complicated, or is otherwise cumbersome. This is the case with software and operating system updates, especially if they come up during the response.
- Some kind of configuration is required periodically, for each activation of the system, or during the response. Examples include inputting wireless network names, passwords, encryption keys, destination addresses for the data streams, data formats, etc.
- The system artefacts have special storage requirements. This is the case with electronics that need to be stored at particular temperature and humidity levels, batteries that self-discharge in storage, etc. Such storage requirements may be acceptable compared to the benefits from the system, but they still represent a disadvantage that system designers should keep in mind.
- The system is not usable for handling daily emergencies. This forces agencies to train responders explicitly, since the option of daily experience is not available. As training with an e-triage system will likely cost more than training with paper-tags, the e-triage system would face a considerable disadvantage.

[8] It is possible to mix marking and monitoring in the same process or artefact, but this must be done without harming the workflows. As an example, paper tags, an artefact for triage, provide form fields for notes and vital values monitoring. Those fields, however, are meant to be filled by medics at the holding area, which is a time-insensitive context, not by triagers in their time-critical context.

- Triage and monitoring data are only readable over the system, or data are not easy to import in the hospital's own patient management system. This includes using proprietary data formats, using proprietary interfaces, as well as not providing redundant access to the data when the system breaks or has not yet been fully installed.
- The system can only be introduced in an "all or nothing" fashion, or requires several organisations or roles to adopt the system at the same time[9]. Coordination among agencies with different ownership, budgets, priorities, and time plans is unlikely. The inability to introduce the system slowly by purchasing only small parts at a time means that organisations would have to either blindly trust the system or simply reject it. Given the limited agency budgets, rejection would be far more likely.
- The cost of the system may simply be too high for the response agencies[10].

Dimension 4: Appropriateness of interaction

A key characteristic of a triage system artefact is its ability to enable interaction among users and groups across time and space[11]. Since e-triage systems enable machine-mediated human-human interaction, they may introduce problems at both the human-machine and the human-human interaction level.

Typical problems and examples include:

- Generic usability problems according to ISO9241 (ISO9241). These may hint at insufficient analysis of the context of use.
- Interactions take too much time and/or resources. We have personally witnessed a proposed e-triage system where responders had to long-press a button for 8 seconds to turn the tag on, then 3 seconds for each color until the desired one, then another 8 seconds to activate the tag. This interaction takes, by itself, longer than the triage time allowed in some countries.
- Using explicit interactions where an implicit alternative is available. An example is the explicit scanning an RFID tag before putting it on the victim, whereas an implicit method is available and has been used successfully with first responders by (Zúñiga 2012).
- A closely related problem arises when interaction with the system replaces interaction with the victim. This is typical of systems where the responder needs to input data on a GUI: both visual focus and the locus of attention are moved away from the victim. Loss of eye contact also makes it impossible to observe, comfort, or reassure the victim, thus breaking a critical human-human interaction.

Dimension 5: Consideration for responders' attitude to IT

First responders, even when they are early adopters in private life, tend to distrust IT on the disaster field[12]. (Adler et al. 2012) report that handling of electronic devices is the biggest stressor in disaster response. E-triage systems need to be explicitly designed to work despite this attitude, and change it. Such design must also be clearly communicated to the responders.

Typical problems and examples include:

- Reliability problems. The most degraded state of an e-triage system must be at least as useful as paper tags. The system designers must also communicate this clearly, providing proof as appropriate.
- Trust problems. The ability of IT-based tools to log every action causes mistrust and worries responders. They fear that the logs may be abused, especially by victims' lawyers suing for profit (The Associated Press 2015). The e-triage system must therefore provide for (some) anonymity.
- Seamless, black-box design of the system or its artefacts. Responders know that, below a certain level, any tool is composed of black boxes. What they perceive as problematic are systems or artefacts that do not allow inspection, recombination, repair on the field, or appropriation of the parts for other purposes (mixing and matching). The design of the system should make it clear how the parts work together and where "the seams" are, making seamful-design (Chalmers 2003) a preferred paradigm.

[9] As an example, e-triage tags that are visible only through AR glasses would force triagers and paramedics to adopt AR glasses simultaneously.
[10] We only report cost as a problem for the sake of completeness, because it is neither applicable nor fair to consider it for research prototypes.
[11] As an example, a paper tag enables communication between triagers and paramedics who come to the same victim (place) later. It also enables communication between treatment area medics and hospital doctors at both a later time and different place
[12] Various sources imply that responders trust and widely use communication technologies (radio, phones, satellites, fax, etc.), but IT is restricted to high-level and remote command posts (Starčević 2015; ITU-D Study Group 2 2014).

Dimension 6: Sound design methodology

Design methodology weaknesses cannot be judged directly by first responders, but they may be the root cause of errors in the other dimensions. We have encountered the following weaknesses in published work:

- Not having defined an explicit risk model during e-triage system design. Triage systems are used in inherently hostile environments. Without a risk model it is not possible to prioritize actual, probable risks from mere theoretical and neglectable ones. Lack of a risk model is the reason why some e-triage systems prevent responders from accessing victim data (in the name of privacy), yet leave their network infrastructure open to DoS attacks by anybody with a portable Wi-Fi router.
- Testing the system in the wrong context, or with the wrong users. Several authors report testing e-triage systems in a lab or hall, using students and other unexperienced civilians in the role of triager, and using printed descriptions of how a victim should be triaged. This testing environment is neither comparable nor generalisable to real disaster response.
- Not accounting for all stakeholders of a triage system. Triagers, medics, and hospital doctors are most often taken into account, but the needs of other responders (firefighters, police, ambulance drivers, etc.) and those of response organisations as separate stakeholders are rarely considered.

Review of state of the art e-triage systems

The above e-triage acceptance dimensions were used by the authors to review the e-triage systems from the state of the art and identify barriers to acceptance. The results are anonymously[13] summarised in Table 1 below. The following general findings apply:

- All of the proposed systems present methodology weaknesses in that they lack a risk model. We did not mark this, so that we could draw attention to the second most common methodology problem: inappropriate testing, using students or other people with no experience in triage, in ideal lab conditions, and on tabletop exercises where victims are represented by printed descriptions.
- Systems using a PDA and/or WIMP GUI do not argue why this is the most usable approach for the intended users, especially given the physical environment, the reported suboptimality of PDAs in emergency use (Turoff et al. 2004), and the cognitive load of the disaster field. In the words of a triager: "When dozens of people are screaming for help all around you, even tearing strips off of a tag might be too much for you to do reliably, let alone fill out a complicated form." (Brownlee 2014).
- Several proposed systems can be used both in disasters *and* in daily emergencies, but they offer a different interface for each case. Considering that "the interface *is* the system" (Monson-Haefel 2009), and that using the same methods and tools in both everyday life and disaster management has a positive impact on the quality of triage (Nagata et al. 2006; The BRIDGE Project 2011) , we wonder why the proposed approaches forego these benefits willfully.

[13]It is not our intention to point fingers but rather to highlight common problems so that system designers can learn from them.

Table 1. Review of proposed systems. The symbol × represents problems in the respective dimension.

System	*1. Complete/appropriate*	*2. Workflow impact*	*3. Org. needs*	*4. Interactions*	*5. IT attitude*	*6. Methodology*	*Notes*
System 1		×	×	×			Requires infrastructure and additional work attaching sensors, all-or-nothing deployment, mixes marking/monitoring, logistics not addressed
System 2	×	×					Takes longer than paper-based triage, requires infrastructure deployment before triage
System 3	×		×				Takes longer than paper, Different interfaces for same role, specifically discourages learning through daily usage
System 4		×		×		×	Requires infrastructure to be installed, mixes marking and monitoring, focuses attention on device, unrealistic testing
System 5	×	×	×		×	×	Unreliable triage data and misleading visualisations, requires pre-existing infrastructure, completely changes the triage workflow, cannot be used in all kinds of events, no risk model
System 6	×	×		×			No victim tracking, no monitoring possible, network reliability depends on attending to IT and prior planning, explicit interaction required
System 7	×		×	×		×	Does not account for unexpected input, not tested in actual conditions, diverts attention from victim, focused on hospital triage, problematic logistics in cross-border events
System 8	×	×			×	×	Automated triage, no influence on algorithm, attending to IT, reported results are theoretical, never tested in real conditions, no role separation, modifies triage algorithm because the technology could not measure certain required inputs
System 9	×		×	×		×	Automated triage with no override, unrealistic testing, holding device influences medic's capability to work, specifically discourages learning through daily usage
System 10	×	×	×		×		No useful degradation possible, requires infrastructure deployment, black-box design, data available only through system
System 11	×	†				†	† No testing reported, no usability details reported, not clear if infrastructure is needed or when it is deployed. Automated triage requested by the client, but not usable for the general case
System 12		×	×	×			Needs infrastructure installation, specifically discourages learning through daily usage, moves attention from victim, unclear usability and reliability in disaster environment

Continued on next page

Table 1. Review of proposed systems (continued).

System	*1. Complete/appropriate*	*2. Workflow impact*	*3. Org. needs*	*4. Interactions*	*5. IT attitude*	*6. Methodology*	*Notes*
System 13	×			×			A good approach, but unfortunately incomplete. Device usage may divert attention from victim
System 14	✳	✳	×	×	✳	✳	✳ Almost no details available. Data may not be accessed outside the system. The type of device and network used may divert attention from victim
System 15	×						System explicitly tackled reliability and logistics issues, but is unfortunately incomplete
System 16	×	×			×		Asks unnecessary questions, doubles the amount of work needed for marking, gives impression of detailed logging
System 17		×		×	×	×	Doubles amount of work for marking, requires attending to IT & explicit interaction, commander is assigned out-of-scope tasks, extremely detailed logging, questionable testing

CONCLUSION AND OUTLOOK

This paper presented the results of a detailed study of emergency response and triage in particular, which aimed at understanding both (i) what responders need from an e-triage system, and (ii) why already proposed, IT-supported e-triage systems have not been adopted in real life. By categorising the problems expressed by responders, the paper presented six "e-triage acceptance dimensions" impacting e-triage systems and illustrated each dimension with typical design mistakes and examples. A review was presented, where state-of-the art e-triage systems were analysed for problems along these dimensions.

The e-triage acceptance dimensions are best thought of as a summarised and categorised knowledge collection of "lessons learned". They can already serve as an aid for e-triage system designers to avoid design pitfalls. For future work, the identified dimensions will serve as basis for a design space in which new approaches can be categorized and evaluated, and where various design aspects can be weighed against each other by importance. The design space may also hint at new system architectures that may have escaped attention so far.

ACKNOWLEDGEMENTS

This work was carried out under the EU FP7 BRIDGE Project, Grant No. 261817, and the BMBF PARADISE Project, Grant No. 16KIS0427.

APPENDIX

The table below lists the dates, places, and kinds of empirical user research carried out for this work.

Table 2. Schedule of user research activities

Meeting	*Date/Place*	*Observation*	*Contextual Enquiry*	*Interviews*	*Focus Groups*	*Sandbox Sessions*	*Blue Sky sessions*	*Prototype Workstations*	*Scenario Walkthrough*	*Expert Reviews*	*User testing*
EUAB Meeting	*27.6.2011, Austria*			✓	✓				✓		
Expert Workshop I	*28-30.9.2011, UK*			✓	✓	✓	✓				
Architecture Workshop	*7-9.11.2011, Germany*				✓			✓	✓		
EUAB Meeting	*28-29.11.2011, Austria*			✓	✓				✓	✓	
Expert Workshop III	*5-7.12.2011, UK*			✓	✓	✓	✓				
Ethics Requirements Workshop	*5.3.2012, UK*								✓	✓	
THW Interview	*12.3.2012, Germany*			✓					✓	✓	
Co-Design Workshop	*15-16.4.2012, UK*				✓	✓	✓	✓			
EUAB Meeting	*3.5.2012, Switzerland*				✓				✓	✓	
Firefighter Interview	*4.5.2012, Switzerland*	✓	✓	✓							✓
NIMBUS Exercise	*11.5.2012, Germany*	✓									
Interoperability Discussions	*25.12.2012, Germany*								✓	✓	
System Demonstration	*22-23.8.2012, Switzerland*	✓	✓	✓	✓					✓	✓
Integration test	*31.8.2012, Switzerland*	✓	✓								✓
System Demonstration	*17-19.9.2012, Switzerland*	✓	✓							✓	✓
EUAB Meeting	*20-21.9.2012, Switzerland*				✓				✓	✓	
Technical Meeting	*25-26.2.2013, Netherlands*									✓	
Firefighter Training	*03.2013, Switzerland*	✓	✓	✓							✓
System Demonstration	*23-24.4.2013, Norway*	✓		✓	✓					✓	✓
Civil Protection Forum	*15-16.5.2013, Belgium*							✓			✓
EUAB Meeting	*28-29.5.2013, Belgium*				✓			✓	✓	✓	
Validation Meeting	*6.8.2013, Germany*							✓	✓	✓	
System Demonstration	*23-24.9.2013, Norway*	✓	✓	✓						✓	✓
EUAB Meeting	*24-25.9.2013, Norway*				✓				✓	✓	
EMS Conference	*25.9.2013, Norway*									✓	
EUAB Commentary	*11.3.2014, Distributed*								✓	✓	
Ethics Workshop	*14.3.2014, Distributed*			✓	✓				✓	✓	
Project Meeting	*7-8.5.2014, Spain*				✓				✓	✓	
Validation	*19.11.2014, Norway*							✓		✓	
Exploitation Workshop	*12-13.3.2015, Netherlands*				✓			✓			
UAV Integration	*29.4.2015, Austria*		✓					✓	✓		✓

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Policy Gaming for Humanitarian Missions

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ABSTRACT

Aid workers increasingly face risks when working in crisis regions. In order to improve effectiveness and safety of humanitarians, it is of great importance to provide a well thought out real-time socio-technical support. Thus, new policies and innovative technological solutions need to be developed and integrated into humanitarian workflows. For the requirements elicitation process to realize this aspiration, we employ a board game approach that confronts players with situations aid workers experience in the field. From the first game session, we learned that the game is a valuable tool. It raises awareness to important challenges and trade-offs that humanitarians face. In addition, it is an effective catalyst for initiating a discussion on which system requirements are needed. Future work will include an update of the board game as well as sessions with the target group of practitioners to inform the development of a socio-technical system for humanitarian aid work.

Keywords

simulation game, humanitarian aid, crisis management, requirements elicitation

INTRODUCTION

The conflict in Syria is one of the largest humanitarian crises of the 21st century. In 2016, an estimated 13.5 million people, including 6 million children, were in need of humanitarian assistance. However, humanitarian access in this and other regions are highly constrained by on-going conflict, shifting frontlines, administrative and bureaucratic hurdles, and violence deliberately targeted against aid workers in contravention of international law, international humanitarian law and human rights law (Humanitarian Response, 2016). Last year in Syria alone, aid convoys delivering goods to the suffering people have been attacked multiple times. In September 2016, an airstrike on an aid convoy near Aleppo, killed twenty civilians including several aid workers and destroyed eighteen trucks containing relief goods. As immediate security measure, the United Nations suspended all aid convoys to Syria. Likewise, the International Committee of the Red Cross declared that this attack has serious repercussions on their humanitarian work in the region (The Guardian, 2016; Aljazeera, 2016).

For protection, international humanitarian aid organizations such as ISRC and the UN agencies rely on minimum operation security standards (MOSS) (ISRC, 2015; United Nations, 2006; WFP, 2009). However, as humanitarian aid work comprises of a complex system with many different stakeholders (local and international NGOs, field experts, host governments, and other authorities), it is alarming that a shared security standard, used by all organizations involved in the workflow of humanitarian aid is yet missing (Armstrong, 2013). Although there is a widely shared and intuitive understanding that proper communication with well working policies and technology is key in order to secure the safety of the aid workers and to support the effectiveness of the aid work, in reality, aid agencies often fail or find it difficult to collaborate (Fenton, 2003). Balcik et al. (2010) provide an extensive overview of challenges in coordinating humanitarian aid efforts. Firstly, the emergence of information technologies like GPS, telecommunication networks, and tracking mechanisms provides opportunities for improved security planning and coordination. This development also creates new safety issues in the humanitarian environment (Armstrong, 2013; Lindenberg and Bryant, 2001). Secondly, coordination activities cost time and money for the aid organizations. As a result, agencies have to weigh costs of participating in coordinative initiatives against the provision of direct services. Thirdly, the coordination of humanitarian aid work is challenged by the fact that the humanitarian system includes a large number of actors (Stephenson, 2005). Not one institution is vested with authority and control to prioritize activities and allocate assets, and inevitably, different organizations have competing multiple interests.

With regard to the effectiveness and efficiency of aid delivery Minear (2002) argues that a number of policy tools are indispensable. Such policies and strategies include strategic planning, information gathering and sharing, resource mobilization, common accountability frameworks, assuring a shared division of labour in the field, and maintaining workable relations amongst the aid organizations and with local authorities. Besides, (Balcik et al., 2010) argues that as logistics is a major component of disaster relief operations, the coordination of the transportation of relief goods is likewise vital for the success of aid work. Still, decision-support systems in humanitarian aid supply chains are not as developed as their commercial counterparts (Balcik et al., 2010).

Furthermore, the nature of crises suggests that humanitarian organizations have to make decisions such as the allocation of resources under severe uncertainty in a highly dynamic environment. Typically, this condition leads to the movement of authority to lower levels and a flattening of the communication network (Turoff et al. 2004). As a result, many decisions are made ad hoc with little considerations of the strategic consequences or possible look-in effects. On the other hand, preserving a hierarchical structure in times of emergency produces even more unfavorable results – e.g. slow response and misallocation of aid (Dynes & Quarantelli, 1976). Therefore, Dynes & Quarantelli (1976) argue that emergent organizations that organize around information flows and break up traditional organizational boundaries are needed for an effective emergency response system. Emergent structures are characterized by greater resilience and more flexible to respond to the unknown. However, designing and implementing emergent organizations remains a great challenge and until today an active line of research as many questions are still unanswered.

Considering specifically the situation for aid workers in Syria, we argue that new policies and innovative technological solutions need to be developed and integrated into humanitarian workflows. To realize this aspiration, we make use of an interactive board game as tool to identify and prioritize requirements. The outcomes of the game play and its debriefing discussion will inform the development of the new system. In this paper, we present the design considerations towards such a game, the outcomes of a first game play session, and outline further steps of our research.

GAMING & REQUIREMENTS ELICITATION

Defining appropriate system requirements is fundamentally important for evolving and re-designing complex systems, specifically in high-risk security environments (Nuseibeh and Easterbrook, 2000). Requirements engineering, in the context of complex socio-technical systems, refers to the systematic process of identifying, specifying, and validating user requirements (Van Lamsweerde, 2001). Here, we focus specifically on the identification of requirements and make the case for employing a gaming approach to support this task. In the following sections, we first present the current best practices of requirements elicitation and secondly focus on the value of gaming in this process.

Best Practices in requirements elicitation

In a nutshell, requirements elicitation describes the process of collecting requirements of a system from users and other stakeholders. Before that, a rigor domain analysis is an inevitable premise before beginning the formal requirements elicitation. The domain analysis aims at providing an in depth understanding of the application domain and includes the identification of relevant stakeholders, as well as their interest and perceptions of problems (Jackson, 1995; Nuseibeh and Easterbrook, 2000). By involving stakeholders in the domain analysis, the current system state and opportunities for improvement can be captured and jointly objectives that the target system should achieve be clarified (Van Lamsweerde, 2001). A good domain analysis is able to identify root causes of problems and provides a complete picture of the socio-technical environment in which humans and technological devices interact (Ross and Schoman, 1977). Following Dietz (2006), the outcome of a domain analysis needs to fulfill the following quality criteria:

- Coherence: the domain analysis should constitute a logical and truly integral context.
- Comprehensiveness: the domain analysis should have a complete coverage of all relevant issues.
- Consistency: the domain analysis should be free of contradictions or irregularities.
- Conciseness: the domain analysis should be compact and succinct.
- Essence: the domain analysis should only show the essence of the problem domain.

Multiple techniques for eliciting requirements are discussed in the literature. Goguen & Linde (1993) provide a comprehensive survey and assessment of different techniques, considering: brainstorming, document analysis, survey/questionnaire, interviews and focus groups, observation, prototyping, and interactive workshops. What is interesting is the notion of conscious and tacit knowledge. Robertson (2001) argues that it is relative straightforward to identify conscious requirements, however, it is more difficult to identify unconscious requirements (requirements stakeholders implicitly assume) and undreamed requirements (requirements stakeholders do not realize are possible) (Robertson 2001). Consequently, she calls for employing different complementary techniques. Briefly, Robertson (2001) suggests that conscious requirements can be effectively obtained from interviews and surveys. However, unconscious requirements can be more readily identified by participatory approaches. Finally, to capture also undreamed requirements, Robertson recommends organizing brainstorming sessions and make use of explorative simulation models.

Furthermore, techniques for eliciting requirements should also be chosen with the characteristics of the domain in mind. As described in the introduction of this paper, the field of humanitarian response is a complex multi-actor setting and involves enormous challenges with respect to inter-organizational communication and coordination (Balcik et al. 2010). What is more, agencies working in conflict areas have to strike a balance between humanitarian and security concerns. Since individual humanitarian agencies only have partial view on the problem, multiple stakeholders needs to be involved in the system design process in order to collecting both new requirements and feedback about existing ones (Saab et al., 2008). A proper technique that can deal with such setting is on demand and we argue that gaming has great potential to fill this gap.

Gaming for requirements elicitation

In recent years, increasing focus has been paid to game based approaches towards requirements analysis, since games have been proven to be an effective tool to collaboratively generate innovative ideas, communicate knowledge, and engage stakeholders across multiple domains. Nevertheless, the idea of adapting a serious gaming approach for user requirements elicitation is relative new and only few applications exist (Marcelino-Jesus et al., 2016). In the following we will discuss the motivation for using gaming for requirements elicitation.

Games facilitate the process of eliciting requirements, because games are able to put requirements for system design in a useful context (van Lamsweerde, 2001). In addition, games provide a safe environment that mimics real life experiences and provides opportunities for participants not only to reflect on their own behaviours, but also to experience other stakeholders' roles (Westera et al. 2008). Knauss et al. (2008) argue that games can illustrate and convey insights that are difficult to gain using other requirement elicitation approaches. A well-designed game is fun to play and able to produce robust and reproducible results. Hainey et al. (2010) concludes that game-based learning is an effective tool, which increases the knowledge level of users and is suitable for requirements collection. Likewise, Fernandes et al. (2012) report promising results suggesting that gaming for requirements elicitation possibly enhances the user involvement in the eliciting process and assures the quality of obtained requirements.

Also, in the humanitarian field, researchers have already successfully adopted similar approaches. Games have been utilized for making the development of information management tools more user centred (Meesters and Van de Walle, 2014; Meesters 2014). Besides, given the inexpensive yet authentic evaluation of the technological solution, the authors argue that games can be used as training environment as well as be part of the dissemination strategy for deploying developed tools into the field.

THE BOARD GAME - PLEHON

Simulation games come in many different formats – from simple card or board games, to extensive role-plays and advanced computerized models of complex systems and situations. In general, a game can be defined as an artefact based on rules, roles, and resources (Klabbers, 2009). More specific, a game represents a system in which players engage in an artificial conflict defined by rules that results in a quantifiable outcome (Salen & Zimmerman, 2004). Games are powerful tools to represent, understand and design complex systems (Bekebrede, Lo, & Lukosch, 2015). They enable human participants to enact a specific role in a simulated environment (Duke and Geurts, 2004) and are often used to train specific skills (Lukosch et al., 2014), transfer knowledge, explore the effect of novel technologies (Lukosch et al., 2015), or develop new strategies or policies.

In our case, we make use of a board game in order to illustrate the role of communication and coordination in humanitarian aid work, and to analyse the workflows needed to collaborate and carry out aid work in an efficient and safe manner. In this sense, the board game serves as a research tool with the aim to understand the field of humanitarian aid work and its needs. For doing so, a game model is constructed from a systems analysis, after which the game is played and the results are transferred back to the reference system (Peters, Vissers, & Heijne, 1998).

We have chosen to use a board game, as a board game is relatively simple to develop, compared to e.g. advanced video games. It can be played in a relative short time period and still can provide a realistic experience of a complex system (see for an example from the logistics field (Kurapati, Lukosch, & Verbraeck, 2015). Games can be distinguished as being either competitive or cooperative in nature (Zagal, Rick, & Hsi, 2006). In our case, the game includes both. One the one hand, the players compete for the highest score in order to win the game. On the other hand, the main goal of the game is to save as many people as possible, which can only be achieved by cooperative behaviour.

The board game developed and used in this study is called Plehon. Plehon represents a crisis area in a fictitious game world, and consist of three locations in need of help: Forestia, Cap City, and Hilltown. Those are represented on the game board (Figure 1), as well as a score indicator and a satisfaction meter for the local government. Stacks of event cards, asset cards, and mission cards are placed in the middle of the board. Four players are playing in equal roles of an NGO that is able to provide assets (blankets, food, and vaccines) to different locations. The mission cards indicate how many assets are needed in which location and how long each aid mission is allowed to take.

A facilitator introduces the game, its goals, rules and roles, and manages the rounds, scoring, as well as introducing the events. The facilitator helps the players with the game play, and encourages for quick decisions. The game is being played round-based, with each player taking actions in turns. The tasks of the players include drawing asset cards and making their operational decisions. Based on the mission information and optionally the event information, the players can either share information and put resources directly into a mission, or put recourses into a convoy first without accouchement. Each player has a limited number of communication tokens and can share their resource allocation decision of the round by spending one token. A meeting (limited to 1.5 min) of all players can be organized, which costs three communication tokens. These tokens can come from different NGOs. If communication is not chosen, the allocation of assets into a mission is invisible for the other players. The game score is based on the number of assets a player allocates to a certain mission. Points are only allocated if a mission succeeds. If a mission fails, no player gains any points. This leaves a certain risk to the decision on the investments of assets into the missions.

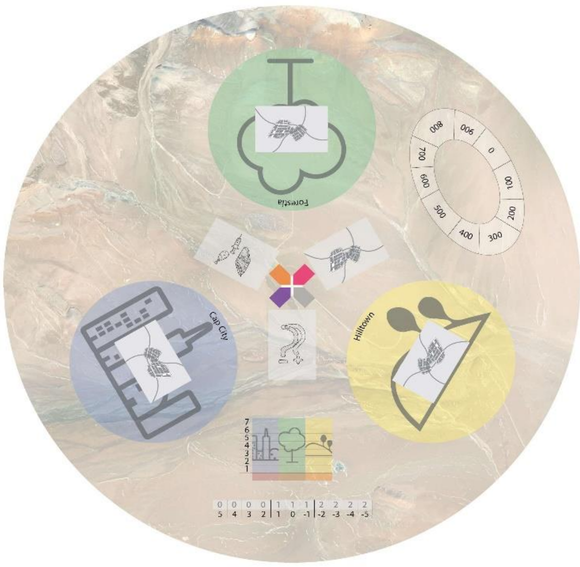

Figure 1. Plehon Game Board

METHODS

The game session was introduced with a scripted briefing, supported by power point slides briefly explaining the problem, the roles, rules, and resources of the game. The whole session was videotaped, and the debriefing was also recorded. In addition, based on the video recording the elapsed time of the different phases was logged. After the game play, the participants filled in the Game Experience Questionnaire (GEQ) (IJsselsteijn, Poels, & de Kort, 2008a). The GEQ is a self-reported instrument to capture different aspects of participants' subjective in-game experience in a convenient and time-efficient manner (IJsselsteijn et al. 2008b). It is constructed modularly. For this study, only the core module was utilized. The questionnaire consists of a set of neutrally formulated 5-Level Likert Scale questions. The core module consists of 33 questions and addresses 7 dimensions of game experience: (1) Sensory and Imaginative Immersion, (2) Tension, (3) Competence, (4) Flow, (5) Negative Affect, (6) Positive Affect, and (7) Challenge (IJsselsteijn et al. 2008a). The de-briefing was based on the JamToday Game Scope card set, developed by the JamToday project (http://www.jamtoday.eu) and ended with an open question round on the experiences during game play.

THE GAME PLAY SESSION

Participants

Eight test persons were invited to the game session. All were researchers, three of which had a background in the area of humanitarian aid, while the others were experienced in game design. The participation was on voluntary basis, and all participants gave their spoken consent that data from the session could be collected in order to evaluate the game play.

Set-up

Four teams of two participants played the game during a facilitated game session. The game session took about 2 hours, and was structured into briefing, game play, debriefing and discussion. The two independent game facilitators began the session with a brief presentation on the humanitarian decision making context. Subsequently, depending on seating arrangements, teams of two were formed, and the facilitator representing the UN OCHA (United Nations Office for the Coordination of Humanitarian Affairs) in the gaming world introduced the rules of the game as well as team and overarching common objectives.

The first few game grounds started with some easy missions to provide the opportunity to familiarize participants with the rules of the game. Then, without interruption of the game play, the missions became more difficult and the game dynamics more interesting. One of the game facilitators continued to play the role of the UN OCHA and supported the participants to comply to the rules of the game. The other facilitator computed the interim scores and publicly announced the scores regularly, which provided the players with feedback on the effectiveness of their actions and strategies. The end time of the game came as surprise for all players allowing no strategic behaviour in the last round. The game facilitator computed the final score and shared their observations, after which the winner was rewarded and asked to explain his/her strategy. Likewise, the other teams were then also invited to share their experiences in the game. Hereafter, to assess the game quality, participants were asked to fill in a game experience questionnaire. Then, the game facilitator opened the debriefing discussion. Based on a list of prepared questions, the group discussion centred around reflection on how well the game translates humanitarian practice, what would have to be changed to improve the game in the future, and how future versions of the game could be used to elicit requirements.

RESULTS OF THE GAME SESSION

Observations during game play

The rules of the Plehon game were quickly clear. Nevertheless, at the beginning of the game, the rounds went slow. This is because participants were engaged in their teams and discussed sensible strategies. The scoring system was not unequivocally transparent and random events were introduced, resulting in some uncertainty that made it difficult to decide for a specific strategy. Players were highly committed to the game, as demonstrated by a player celebrating a first victory, accompanied by envious glances from opposing teams. The atmosphere was serious and concentrated, while participants tended to play primarily cooperatively. The option for coordination meetings was only used after a massive overspending of resources occurred and not activated before more than 30 minutes of game play. The discussion was organized and focused; quickly all teams agreed upon a short-term strategy for the on-going missions that were complied to. Shortly after, the next joint meeting was initiated. Again, the outcomes were implemented, but long-term strategies were not discussed. In the end, all lives were saved but due to a lack of communication, cumulatively 26 resources were overspent, which could have been used to support others. In the debriefing, the facilitators addressed the painful subject that one team considered to deliberately let some die in one place and other teams were talking about their personal score instead of the people they could potentially safe.

Game Experience Questionnaire (GEQ)

Scores for the dimensions were computed as the mean score of respective question items. Due to the limited number of subjects (N=8) that participated we report stacked bar plots with contrasting colour schemes. The results (Figure 2) suggest that overwhelmingly players find the game stimulating and had fun playing the game according to the very high score on positive affect and low values for negative affect. However, players felt only fairly competent in what they were doing. This outcome may be explainable by the low number of players with experience in the humanitarian context but likewise could be attributed to the quality of the game. The score for immersion is moderately high and for a simple first version of a board game respectable. The average score for flow suggests that there is room for game design improvement.

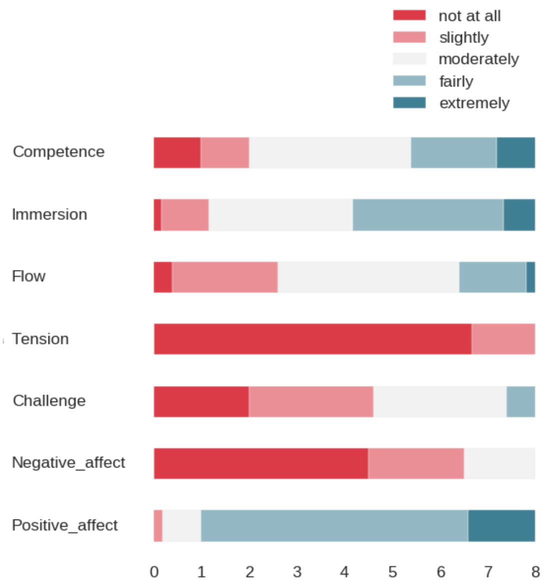

Figure 2: Descriptive results of the core module of the GEQ

To address this shortage, as described, a discussion was organized aimed at reflecting on possible game improvements. Finally, the score on challenge clearly shows the perception that the game was not challenging enough and therefore also not as competitive as intended. Social presence, commonly defined as social connection to other entities, is an important aspect of gaming experience. The findings from the survey are supported by the debriefing session. In summary, the Plehon game provided a meaningful and at the same time engaging learning experience. The level of difficulty was rather too easy and the level of immersion is expandable. Nevertheless, it is respectable for the first simple version of a board game.

Observations during debriefing

The semi-structured debriefing session was focused on assessing the quality of the board game as tool for requirements elicitation. The main objectives of the game are twofold, namely to make participants aware of the crucial role of communication in humanitarian aid work and its usefulness for requirements elicitation based on the workflows of humanitarians. The session was opened with a question regarding whether these main goals of the game were reached. All participants agreed that the game very well displayed the importance of communication to reach shared goals and the difficulties to allocate resources when communication was impeded. Furthermore, the participants noted that the game was fun to play and that there was a clear learning process regarding strategies based on the actions allowed in the game and the feedback given by the scores.

However, the game was perceived as not detailed and comprehensive enough to be useful for requirements elicitation. One criticism that was voiced concerned the unrealistic simplification that communication in the game was modelled binary (either on or off). Speaking from own experience in the field, one participant explained there are various means of communication used and numerous challenges concerning the communication present in reality, for instance language barriers, interpretation and implementation of decisions, and pressure of time. In short, there are more shades of grey than only on and off.

Furthermore, several participants said that more details needs to be added to make the game more realistic particularly with respect to logistic operations. In addition, some players reported that during the round, there was relative limited interaction and hence at times it was boring to just watch people thinking. Asked whether the game was challenging enough, participants reported that it was challenging to find an appropriate balance between competition and cooperation – win the game or save as many lives as possible. However, some saw the missions as too easy, because players could often overspend on missions without consequences. It was concluded that more difficult missions would support the objectives of the game better. There were different perceptions on whether the game provided sufficient consistent strategic options. The majority of participants agreed that they played overall cooperatively and nice to each other. Would the game be repeated, some players voiced they were eager to test the effectiveness of more advanced strategies such bluffing (e.g. not following agreements).

Suggestions for improving game

Hereafter, participants were asked for suggestions and recommendations for improvements to be implemented in the next version of the game. Already during the game play, the suggestion had been made to limit the decision time for each team e.g. with an hourglass or to draw cards all at the same time.

One participant with extensive experience in the humanitarian sector, proposed to add the internal struggles within organizations to communicate, interpret information and take appropriate action. Adding this aspect, the game would better mirror how practitioners are sandwiched between different stakes and influences and create more interesting dynamics having to manage information flows at two fronts. The workflows of humanitarian aid workers that regularly attend internal as well as inter-organization coordination meetings (cluster meetings etc.) could be translated into the board game by establishing a single point of inter-organizational coordination. For the rest of the time, players could be situated within their teams discussing and managing their own organization. Challenges that could be addressed within their organization include the accountability for decisions, handling of logistics, and dealing with donors or headquarter demands.

This core idea could be refined and extended by limiting the time of coordination meetings. Another suggestion was to introduce different roles (manager, logistician, technician,) and characters (e.g. evil, unmotivated, incapable) within organizations that do not necessarily need to be disclosed. Furthermore, organizations could be made specialized by default or strategic decisions during the game by the team. Specialized organizations would have their respective core competences and deficiencies and would add another dimension of strategic options. Other proposed changes to make the game more realistic were to raise and diversify the types of resources, for example add rescue teams, personal vehicles, and trucks for the transport of relief goods.

Based on their observations, participants suggested to introduce more dynamic elements and diverse event cards that could impact all players as well as only individual organizations (teams). On the other hand, participants also warned that too many activities would be confusing and make the outcomes of the game random. Another crucial aspect suggested to be considered was that in rural areas it takes longer and more assets to save fewer lives. This is one of the fundamental problems of humanitarian interventions, which leads to a misallocation of resources towards easy targets in urban regions.

It was suggested to provide room for participants to improve their own processes and learn from communication failures, by creating themselves tools they need and adopting techniques like taking notes, or introducing the cluster mechanism within the game play. Finally, one participant suggested that players should be co-located and modern communication technology should be introduced into the game.

In summary, the participants agreed it was interesting and engaging to play the game. The game represents a great basis on which improvements and extension could be built. Workflows of humanitarian aid workers are in reality more complex and dynamic and hence more detail should be added to the game. To balance the trade-off between complicated and difficult to understand rules and the ability of the game to represent reality, the complexity of the game could be gradually or stepwise increased after a few rounds. Thus, players could understand the backbone of the game before being challenged with new difficulties.

DISCUSSION AND CONCLUSION

In this research, we adapted a simulation gaming approach for user requirements elicitation in the humanitarian context. The game was designed as a simple board game for 4 teams, addressing communication needs in humanitarian aid work and targeting explicitly practitioners and policy-makers. The game’s quality was evaluated based on the analysis of video-recordings of the game play including debriefing and by surveying participants. These two evaluations were complementary and mutually supportive. The game Plehon is perceived as highly engaging and supportive to demonstrate the need for communication in its context, humanitarian aid work. The game’s design is able to capture two essential aspects of complex socio-technical systems of humanitarian aid work. On the one hand, the game is able to show the challenge humanitarian aid workers face in allocating limited resources while dealing with multiple external risks and uncertainties as well as impediments of communication. On the other hand, the game illustrates that humanitarian aid work, in spite of the shared commitment to provide aid to as many as possible, is also a competitive, in which NGOs seek for donor support, recognition and individual aims. As reflected in the game, this leads to strategic behaviour and can make collaboration and trust difficult. Humanitarian organizations need to recognize and balance between these conflicting objectives.

The current version of the game is useful in an early stage of requirement elicitation, especially when the domain – humanitarian aid network – is complex and not well understood by the researchers. Based on the game observation presented above, using the game can be considered as a sufficient catalyst for initiating discussions among participants and subsequently for generating requirements for needs. In the facilitated debriefing, the participants made valuable suggestions on how to improve the game's fidelity and how to enhance the usefulness of the board game in identifying and prioritizing tangible requirements. Overall, we can state that the game supports the goal to represent an important part of humanitarian aid work and provides an experiential learning experience.

In future research, based on this input, we will explore how realistic the game can and needs to be designed for requirements elicitation. The first design steps in this direction include a more realistic map as game board, as well as the distinction between a central coordination meeting point and the discussion within the own teams. We will further explore whether and how combining the classical board game with computer-based game elements affects the game experience and fidelity. Here, we are especially interested on whether the computer-based game elements influence flow and immersion. As we assume that the useful technological support for the facilitator makes the feedback for the players somehow intransparent, we will also explore a game version without IT support, and with direct feedback. To achieve a stronger focus of the debriefing discussion on current and future system requirements, we intend to introduce another decision-layer allowing players to invest into different technical and organizational innovations. Therefore, we already developed an inventory of technology that is currently in place, as well as possible alternative technologies. The challenge for participants will be to balance the various trade-offs of these innovations and manage with limited resources. By adding this decision layer, it would also increase the dynamism of the game and may lead players to make different tactics for field operations. This will provide useful insights into the emerging organizations in humanitarian missions. We will assess the improvements of the game based on qualitative criteria and by statistical analysis of the GEQ scores. We are planning to facilitate several gaming sessions with practitioners from different organizations and with diverse backgrounds. A first test session with humanitarian aid workers is already planned. This setting will contribute to demonstrate the benefits of an elicitation process using a simulation gaming approach compared to results obtained with conventional methods.

ACKNOWLEDGMENTS

We thank the students Fanny Bot, Birgit Ligtvoet, Bart Staats, and Evangelos Theocharous, of the game design project at TU Delft, for the design of the prototype of the Plehon game, and for the facilitation of the game play session. This research has partly been funded by the European Union's Horizon 2020 research and innovation program under grant agreement No 700510.

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Improving Dynamic Information Exchange in Emergency Response Scenarios

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ABSTRACT

Emergency response scenarios are characterized by the participation of multiple agencies, which cooperate to control the situation and restore normality. These agencies can come from diverse areas of expertise which entails that they represent knowledge differently, using their own vocabularies and terminologies. This fact complicates the automation of the information-sharing process, creating problems such as ambiguity or specialisation. In this paper we present an approach to tackle these problems by domain-aware semantic matching. This method requires the formalisation of domain-specific terminologies which will be added to an existing system oriented to emergency response. Concretely, we have formalised terms from the UK Civil and Protection Terminology lexicon, which gathers some of the most common terms that UK agencies use in these scenarios.

Keywords

Query matching, dynamic information exchange, domain-aware matching, domain-specific terminologies, emergency-response extension

INTRODUCTION

Emergency Response (ER) scenarios usually involve the participation of several organisations which collaborate to address the crisis. Although collaboration is common in these scenarios, the exchange of information between participating organisations still presents several challenges.

Manoj and Baker identified in (Manoj and Baker 2007) that ER scenarios present communication challenges according to three categories: *technological* (technologies that agencies use to communicate between them, for example, when they do not use the same radio frequency); *social* (sharing and dissemination of information is problematic due to the lack of common vocabulary between response organisations) and *organisational* (how information flows across organisation's hierarchies). Allen et al. added that one of the most significant challenges regarding automated exchange of information (interoperability) is caused by problems with heterogeneous semantics (e.g., an H on a map is related to a hospital for the paramedics while for the fire brigade this represents an hydrant). This causes difficulties when they share maps (Allen et al. 2014). In part, these problems arise because each agency represents knowledge in a particular way, using its own terminology to describe its domain accurately.

The diversity of representations is not solely a characteristic of ER scenarios. This trouble appears in most areas, for example, it is a common problem in the fields of medicine or biology (Beisswanger and Hahn 2012). In order to tackle these problems researchers from the ontology matching field focus on finding solutions to these problems. See, for example, (Euzenat, Shvaiko, et al. 2007).

Essentially, these approaches try to match different words from diverse sources that are used for the similar purpose (words with similar meaning). Although there are many advances which allow the integration and understanding of resources expressed in different terminologies, there still are several problems that are unresolved. Examples are *ambiguity*, when the same word or symbol represents a different concept depending on the domain, or *specialisation*, when one terminology represents knowledge in a more detailed way than another one. Apart from the mentioned examples, there are others problems like the integration of *multilingual* resources (Rexha et al. 2016), mismatches due to *cultural aspects* (Gracia et al. 2012) (these are concepts specific of a region or a country and they do not exits or are different in other countries) or *large-scale evaluation* (Shvaiko and Euzenat 2013).

The implementation of matching techniques in ER scenarios is not trivial due to issues such as:

- *Privacy constraints*, which restrict the access to some parts of agencies' data sources. This impedes the possibility of carrying out matches between entire datasets, so it is necessary to assume that we have to manage with incomplete data.
- *Dynamic information*. The information is continuously changing so it is necessary to carry out the matching process on the fly.
- *Impractical prior alignment*. Pre-alignment is feasible and sensible for agencies interacting very frequently but intractable otherwise and impossible with agencies for which there was no anticipation of interaction prior to the response.

Despite these considerations, in ER scenarios there are many situations in which matching techniques can be useful. The situation we are particularly interested in is *querying*, where a source agency (the sending agency) sends a query to one or more other target agencies (the receiving agencies) to gather information that they need. If it does not know the data structures of the receiving agency/ies in detail, or they have changed, or a general query is sent to several target agencies, it is likely that this query will fail because it will be built without a precise knowledge of the data structures used by each target agency unless extensive pre-alignment has occurred.

(McNeill et al. 2014) proposed CHAIn, a system which makes use of ontology matching techniques to carry out query rewriting on the fly. CHAIn is located locally within the receiving agency, and is therefore able to access all of that agency's data without any security concerns. When a query comes in that fails to elicit a response, CHAIn will use matching techniques to find approximate matches within the receiving agency's data sources and rewrite the query accordingly, so that a relevant response can be returned to the sending agency. It might be considered as a first step of automating the exchange of information in ER scenarios. CHAIn is designed to act dynamically, and because it is located locally within each agency it does not require agencies to share their data beyond providing responses to queries, so addresses the two issues above. However, the issues of ambiguity and specialisation still remain because they arise from the specific contents of each data source.

This paper introduces an approach to improve the performance of CHAIn in the domain of ER, tackling ambiguity and specialisation by adding domain-aware (DA) semantic matching. Our hypothesis is that *adding DA semantic matching into CHAIn significantly reduces the mismatches produced by ambiguity and specialisation*. Moreover, this approach *helps to find correct matches that might otherwise be missed*. As a result, a new version of CHAIn with DA functionality will be released as domain-aware CHAIn (DA-CHAIn)[1].

Considering that we are going to use this system for data sharing between ER agencies, we also have to enrich it with some of the most common terms used in these scenarios. In particular, we have formalised some terms contained in the lexicon of the UK Civil Protection Terminology (UKCP)[2] in order to make these accessible to DA techniques.

The paper is organised as follows. The next section presents a motivating example. After that some basic notions about domain-aware matching are outlined in the following section. The approach of extending background knowledge by formalising domain-specific terminologies and the development of an ER extension are explained in next two sections. The following section introduces the evaluation methods that will be carried out to test the approach. The paper finishes with related work and conclusion sections.

MOTIVATING EXAMPLES

In ER scenarios such as natural disasters, agencies usually share information because one agency's information might be useful to another one. It is frequently the case that practitioners from different organisations call to other agencies' representatives to ask about the status of a specific incident.

[1]https://github.com/francisjqr/DA-CHAIn
[2]https://www.gov.uk/government/publications/emergency-responder-interoperability-lexicon

For example, in a flood scenario, ER agencies need to know information such as which roads are cut off, what is the forecast for next hours, what the levels of the rivers are, and so on. Currently, such work is carried out entirely through human interaction. We understood from our interactions with the Resilience Department of the Scottish Government that the typical approach is to write new and relevant information on whiteboards in the control room, and then using this information in the decision-making process.

Currently, this process is time consuming, and practitioners often miss pertinent data because they are not aware of its availability. This precarious method puts even more pressure on practitioners, who have to make decisions being aware that a wrong choice may be fatal for people's lives.

These issues could be significantly relieved by automating data sharing in ER scenarios. A major problem to be solved, however, is that every organisation has its own terminology. This is useful an important for agencies because these terms properly describe their tasks and work. However these terms may not be automatically compatible with data from other sources and may be misleading and difficult to understand for people from other domains.

For example, Figure 1 depicts how the fire brigade and the police represent different *Command Levels*.

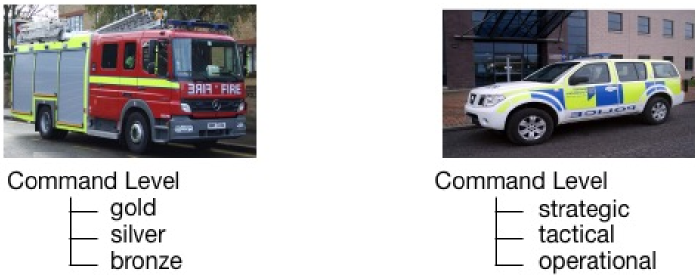

Figure 1. Example of diverse knowledge representation

We can see how they use distinct terms for referring to the same concepts. Attempting to infer a relationship between these terms automatically by using standard lexical resources would fail because they are not obviously related, and even for a human to link them depends on that person having domain-specific knowledge.

Another example of heterogeneity is ambiguity where the same word is used in several agencies' vocabularies, but the meaning is different depending on the organisation. Imagine an international emergency scenario where agencies from different countries are involved. If organisations from the United States (US) and the United Kingdom (UK) have to exchange information they will have a problem with the meaning of the acronym *CIA* because it is distinct depending on the source. Thus, for WordNet[3] (Fellbaum 1998) and the Government of the US, this acronym means *Central Intelligence Agency US*, while for the UK agencies (UKCP lexicon), this means *Community Impact Assessment*. Table 1 shows the meanings from both sources.

CIA	
WordNet 3.1	**UKCP Lexicon**
Central Intelligence Agency US	Community Impact Assessment
An independent agency of the United States government responsible for collecting and coordinating intelligence and counter intelligence activities abroad in the national interest; headed by the Director of Central Intelligence under the supervision of the President and National Security Council.	Procedure to identify the impact a police operation or response may have on communities, including actions necessary to overcome potential negative effects either before or after the deployment of resources, and to specify primacy for community engagement with respect to each element of the operation or response.

Table 1. Example of ambiguity

Yet another example is agencies using different degrees of knowledge representation (KR) in their vocabularies (specialisation), for example, when an amateur forecast society exchanges information with a professional forecast agency. In this situation, the professional agency may have a more detailed vocabulary than the amateur one, which

[3]WordNet is a domain-independent lexical resource. http://wordnet.princeton.edu

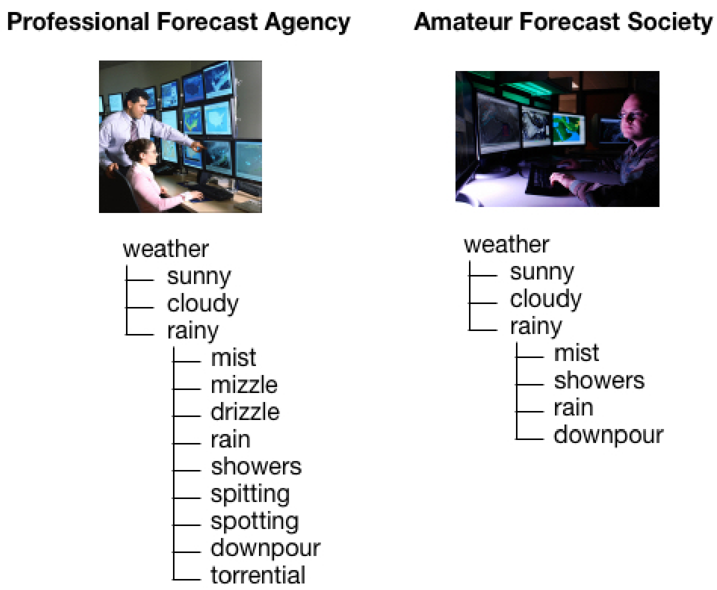

Figure 2. Example of specialisation

makes finding correspondences between the terms of both organisations non trivial. Figure 2 depicts part of the terminologies used by both organisations.

Keeping in mind these motivating examples, in next section we present an approach to tackle automation problems in the process of information exchange between agencies.

DOMAIN-AWARE DYNAMIC QUERY MATCHING

Problems such as those evoked in the previous section are typically solved by ontology matching techniques. Given two schemas with the terminologies of two agencies, the main purpose of ontology matching is to assign correspondences between the elements (nodes) of both schemas. These correspondences are called *matches or alignments* and indicate that two nodes are related. That is, they have similar meanings, so they belong to the same concept. An example of word matching might be the words *river* and *creek* because both words mean a kind of *watercourse*. In order to carry out the matching process, the matcher receives as input two schemas and produces as output the alignments between both schemas. The matcher needs a resource, the Background Knowledge (BK), which contains knowledge of the terminologies, in order to conclude whether or not the natural-language labels of nodes between the data schemas and the query schema have the same meaning.

This is the problem that CHAIn's matcher deals with. In the case of CHAIn it is matching the schema of an incoming query against the schema of a target data source, using both structural and semantic matching techniques. CHAIn is built on top of the Structure Preserving Semantic Matcher (SPSM) (Giunchiglia, McNeill, et al. 2008), which in turn is build on the semantic matcher S-Match (Giunchiglia, Shvaiko, et al. 2004). This matcher is designated for so-called lightweight ontologies (Giunchiglia and Zaihrayeu 2009) that are tree-shaped. SPSM adds standard tree-edit distance techniques (Bille 2005) and a structure-preserving constraint, which make the tool better suited to schema matching. S-Match uses WordNet as BK, taking advantage of the semantic relations defined there to carry out the semantic matching process.

WordNet (Fellbaum 1998) is one of the most extensive domain-independent lexical resources because of the huge number of nouns, adjectives and verbs that are included. Its main characteristic is that it is more focused on the meaning of words than on the form of words. This resource represents concepts by *synsets* which consists of sets of words which are synonyms. Thus, all elements of a synset are included in the same concept, and so they have the same meaning. WordNet is a directed acyclic graph formed according to the following semantics relations: *hypernymy* (superconcept of another concept, for example *motor vehicle* is the hyponym of *car*); *hyponymy* (subconcept of another concept, for example *car* is the hyponym of *motor vehicle*); *meronymy* (one concept is part of another one, for example *air bag* is meronym of *car*); *holonymy* (one concept has/includes another one, for example *car* is holonym of *air bag*).

However, as we discussed in the motivating example section, WordNet is only sufficient in very general situations and it will not be able to deal with ambiguity and specialisation when dealing with data sources using domain-specific terminology, hence the need for DA-CHAIn. First of all, in order to deal with specialisation, we are going to extend the current S-Match's BK adding domain-specific terminologies in order to enrich the BK with terms that ER agencies use to represent their knowledge. Secondly, we extend the matcher with *domain-based word sense disambiguation* functionality, based on our earlier work as presented in (Bella et al. 2016). This allows the matcher to reduce the ambiguity of terms based on domain information. This second aspect of domain awareness is not covered in this paper. These extensions allow us to tackle both ambiguity and specialisation, as depicted in Figure 3.

For example, regarding the ambiguity problem described in the previous section (see Table 1), if the matcher knows the domain of the acronym *CIA*, it can decide whether the term refers to the US agency or to the meaning in the UKCP lexicon. In addition, this extension is also relevant to matching words that are not related yet, because of the lack of lexical information of these words in the BK (see Figure 1) and to infer matches when the specialisation problem appears (see Figure 2).

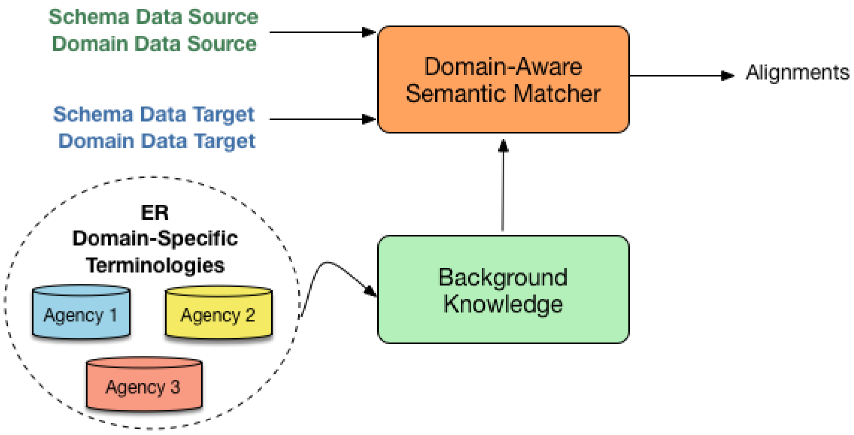

Figure 3. General schema of a DA matcher with the ER extension

BACKGROUND KNOWLEDGE EXTENSION PROCESS

The extension of a BK with domain-specific terminologies is useful for tackling specialisation. However, the selected terms have to meet some constraints to preserve BK's integrity (maintaining consistency between elements' relations). The process of extending a BK consists of the following steps:

1. Selection of terms.
   First of all, it is necessary to select the terms to formalise. These should be terms that are specific to a particular domain (e.g. the fire brigade, the police or the army). For this work, we are taking terms from the UKCP lexicon.

   Each of these terms must have *label* (primary term), *definition* and *provenance*. An example of term may be *agency*:

   - *Primary term*: Agency.
   - *Definition*: A generic term, widely used as synonymous with organisation.
   - *Provenance*: Civil Contingencies Secretariat (CCS).

   Optionally, there are other attributes that might be interesting to formalise such as *acronym, version, notes* or the *jurisdiction* to which the term is restricted.

2. Check that new terms are not represented in the BK.
   Once the terms to formalise are selected, the following phase involves going through every single term to verify whether it is currently represented in the BK or not. This point is crucial because if we create new concepts or senses that already exist in the BK we are increasing polysemy and redundancy, and in some cases violating the BK integrity. For this reason, we need strong arguments for creating new entries in the BK.

This phase is formed by two tasks:

(a) *Identifying term's hypernym/s.* Analysing the definition of the given term (meaning), we can identify the hypernym of the term. It is important this identification to understand the meaning of the term and how can it be integrated in the BK.

(b) *Linking the term to existing terms in the BK.* At this point we have to seek our term (word) in the BK and check whether it is included or not, and if it appears, it is necessary to verify whether the term's meaning in the BK is the same as our term's definition. The decisions to make depending on each case are described as follows:

a *The term is not in the BK.* After looking for the term in the BK the search did not return any result, so our term's *label* does not exist in the BK. At this point, two cases are possible:

- *The concept is currently represented in the BK*, so it is necessary to link the new term to the concept.
- *The concept is not represented in the BK*, therefore the new term is added to the BK creating an associated concept.

b *The term is currently in the BK.* The search of the term in the BK has retrieved one or more senses, so we have to check if any sense has the same meaning as our term. This new verification produces two new scenarios:

- *The term has the same meaning of a sense.* Because the term is currently in the BK with the same definition as our term, we do not have to do anything.
- *No sense has the same meaning as the term.* In this case we have to double-check if the concept is represented in the BK or not. This is the same case as the scenario described before in "2.(b).a" (*The term is not in the BK*), so we have to follow the mentioned guidelines and act depending on the case. A new sense of the word has to be added independently whether it is necessary to create a new concept or not.

3. Double-check terms relations.
Once all new terms are added into the BK, in this phase we have to double-check that all semantic relations have been taken into account. Essentially, in the previous phase we identified the semantic relations between each new term and the terms included in the BK. Nonetheless, it is also necessary to specify the relations of the new terms that are interrelated. For example, in the UKCP there are terms that include in their definitions others terms defined in the lexicon or terms that are synonyms. Therefore, we have to go again through all new terms in order to ensure that all of these relations are considered.

4. Representation in the BK format.
Once we have the terms that we are going to formalise as well as their relations, the next step consists of representing these terms in the BK's format. The output of this step is a file compatible with the BK.

5. Integration of these terminologies into matcher's BK.
In this step, the file which contains the specific terms is plugged in the BK. In our case, we are using a tool called DiverCLI[4] which is capable of plugging new terms into WordNet.

EMERGENCY RESPONSE EXTENSION FOR WORDNET

The process explained in the previous section has been applied to develop an ER extension for WordNet. In particular, we have selected terms from the UKCP lexicon. This lexicon is a collection of more than 725 terms used by UK agencies during ER scenarios. Each entry in the lexicon contains: the label of the term, denoted as primary term; version of inclusion or revision; source and definition. Moreover, there are some terms that also have abbreviations or acronyms, notes on definition and the jurisdiction to which the term is restricted. There are some definitions which reference particular terms that have been defined in the lexicon. These terms are represented in bold to be distinguished from general terms. Table 2 shows an example of the terms: agency, air ambulance, medevac and responder as they appears in the UKCP lexicon. Specifically, the entries of the terms in this example come from two different sources: the Civil Contingencies Secretariat (CCS) and the Environment Agency (EA). The formalisation of this example is currently online[5].

[4]http://diversicon-kb.eu/tools#divercli
[5]https://github.com/francisjqr/ER-Wordnet-Extension/blob/master/illustrativeExample.xml

Primary Term	Abbrev.	Vers.	Source	Definition	Notes	Jurisdiction
Agency		2.0	CCS	A generic term, widely used as synonymous with organisation.		
Air ambulance		1.0	CCS	Aircraft (usually a helicopter) used primarily to transport medical or paramedical staff to the **site** of an **incident** or **emergency** and **casualties** to specialist trauma centres and/or **designated hospitals**		
Environment Agency	EA	2.0	EA	The Environment agency's role is to protect and enhance the environment as a whole in England and Wales. As part of this role, they are also a nuclear regulator in respect of controlling discharges to the environment. An executive non-departmental public body responsible to the Secretary of State for **DEFRA**.	Note: in Scotland, this role is performed the SEPA, the Scottish Environment Protection Agency.	*England and Wales*
Medevac		1.0	CCS	Abbreviation for Medical Evacuation (of casualties by air)		
Responder		1.0	CCS	Organisation required to plan and prepare a response to an **emergency**.		

Table 2. Entries in the UKCP lexicon

We have been collaborating with the Resilience Department of the Scottish Government to elaborate an ER extension for WordNet. We have released a first version with 100 terms of the UKCP lexicon (Quesada Real 2017), which is a representative subset of the whole lexicon. This resource is available on a repository[6] which will gather all the ER extensions that we will develop for our research. These extensions can be used by the ER community so that agencies can use them for their own purpose, allowing organisations to carry out automated reasoning or processing in ER scenarios.

EVALUATION

The hypothesis to be evaluated in our research is that *adding DA semantic matching into CHAIn significantly reduces the mismatches produced by ambiguity and specialisation*. Once we have finished developing DA-CHAIn and integrated the ER extension into it, we will need to evaluate the performance of the system. To do this, we are going to define several case studies, which represent ER scenarios of prior events, together with practitioners from the Resilience Department of the Scottish Government. These will be based on the floods that happened in Scotland in the winter of 2015/2016. These case studies will represent the interaction between ER agencies with heterogeneous KR in situations where the communication failed due to ambiguity or specialisation problems. We are going to use agencies' schemas as well as their data to define gold standards for the evaluation.

Our approach will be evaluated attending to two criteria. On the one hand, it is necessary to test the performance of S-Match with DA functionality. These tests will consist of comparing the precision and recall, concerning the defined gold standards, of both matcher's versions. On the other hand, after the matcher evaluation, we have to evaluate the performance of DA-CHAIn comparing it with CHAIn. To do so, the same case studies will be run in both systems and several practitioners, based on their experience and expertise, will evaluate the relevance of the retrieved responses. Since this process is quite subjective, we have to recruit a panel of practitioners for the evaluation.

RELATED WORK

The work in this paper is concerned with the extension of existing matching techniques with domain-aware information in order to tackle problems like ambiguity and specialisation in ER scenarios.

[6]http://diversicon-kb.eu

There are many proposals for generating matching between diverse ontologies (Shvaiko and Euzenat 2013). For this reason, we have to establish what approach or combination of approaches adjust better to our specific problem (Otero-Cerdeira et al. 2015). Thus, we build our system on CHAIn, defined in (McNeill et al. 2014), which takes into account the characteristics of ER scenarios. Thus, it tackles the heterogeneity of structured terms and carries out dynamic and local matching, which were crucial aspects in our decision.

Although CHAIn produces good results, there are occasions when it fails to find mappings, in part due to issues of ambiguity and specialisation, a common problem in ontology matching (Sabou et al. 2006). These troubles are caused by the lack of domain information in situations where these issues appear. Indeed, these problems increase in scenarios where there are agencies from multiple domains. There have been attempts from the ontology matching field trying to solve these problems by enriching matching approaches with knowledge of ontologies' domains (Slabbekoorn et al. 2012). One example of these works was proposed by McCrae et al., who used domain information from Wikipedia[7] articles to improve the performance of adapting an ontology into a different cultural context in multilingual problems for machine translation (McCrae et al. 2016). In the same way, León-Araúz and Farber present an approach to describe concepts and terms from different domains and with cultural constraints to carry out cross-lingual correspondences using context features (León-Araúz and Faber 2014).

Even though these techniques can improve the correctness of matches, it is necessary that our BK identifies which terms belong to each domain. One of the most extended online lexical resources and the one used by CHAIn's matcher as BK is WordNet (Fellbaum 1998). There are some works focused on providing WordNet with domain information. Magnini and Cavaglià integrate subject field codes into WordNet, annotating noun synsets. This allows the grouping of synsets of the same domain (Magnini and Cavaglia 2000). Likewise, Bentivogli et al. develop the WordNet Domain Hierarchy, which is a language independent resource, composed of 164 domains such as Architecture, Sport or Medicine (Bentivogli, Forner, et al. 2004). In the same way, Strapparava and Valitutti propose tagging synsets which represent affective meanings, in order to provide a lexical representation of affective knowledge. González et al. for their part improve WordNet domains by an automatic graph-based method which propagates domain information through the knowledge base (Gonzalez-Agirre et al. 2012). Also, Gella et al. construct a domain-specific and multilingual corpora aligning WordNet domains and topics with Wikipedia categories (Gella et al. 2014). Moreover, there are some works which extend WordNet with specific terminologies from architecture (Bentivogli, Bocco, et al. 2004) or maritime domain (Roventini and Marinelli 2004). Despite the number of domains that currently exist in WordNet, the ER domain is not included. The creation of this domain as well as an extension with ER terminologies might be beneficial for those agencies that use WordNet resource for different purposes, e.g. natural language processing. Furthermore, the adaptation and definition of DA matching techniques entail a theoretical contribution in the ontology matching field. The integration of DA functionality into CHAIn supposes an advance to improve the communication between agencies in ER scenarios reducing problems derived by ambiguity and specialisation.

CONCLUSIONS AND FURTHER WORK

The difficulty of exchanging information between agencies in ER scenarios because of the heterogeneity of KR makes it necessary to develop resources which help to palliate the problems these leads to.

In this paper, we have presented a proposal for tackling these by DA semantic matching. Concretely, we focus on ambiguity and specialisation problems. This approach will be implemented in the query rewriting system CHAIn, as DA-CHAIn version. To do so, we have produced an ER extension from terminologies contained in the UKCP lexicon, in order to extend the BK of CHAIn's matcher. This reduces the communication problems mentioned above.

Regarding further work, this resource will be used to improve semantic matching between ER organisations' schemas. Moreover, it will be beneficial to increase the ER extension with terms from more organisations, including agencies from different countries. The next step will be towards working with multilingual terminologies which are crucial to improve the exchange of information in cross-border or international emergency response scenarios.

ACKNOWLEDGEMENT

The authors wish to thank the members of the Resilience Department of the Scottish Government for interacting with us during last months. The research is supported by the European Commission with the grant agreement No. 607062 (ESSENCE Marie Curie ITN, http://www.essence-network.com/).

[7]https://www.wikipedia.org

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DoRES — A Three-tier Ontology for Modelling Crises in the Digital Age

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ABSTRACT

During emergency crises it is imperative to collect, organise, analyse and share critical information between individuals and humanitarian organisations. Although different models and platforms have been created for helping these particular issues, existing work tend to focus on only one or two of the previous matters. We propose the DoRES ontology for representing information sources, consolidating it into reports and then, representing event situation based on reports. Our approach is guided by the analysis of 1) the structure of a widely used situation awareness platform; 2) stakeholder interviews, and; 3) the structure of existing crisis datasets. Based on this, we extract 102 different competency questions that are then used for specifying and implementing the new three-tiers crisis model. We show that the model can successfully be used for mapping the 102 different competency questions to the classes, properties and relations of the implemented ontology.

Keywords

Crisis Ontology, Situation Awareness, Emergency Model, Events, Reports.

INTRODUCTION

In emergency crises a large amount of information is collected, processed and analysed in order to help individuals and humanitarian organisations to better understand situations. Typically, information is managed through a software platform that helps responders to find key information quickly and efficiently. This means that collected information needs to be understandable by both computer software and humans.

Data is generally collected from different information sources or directly from individuals and then processed into reports that summarise existing information into a human readable format such as plain text. Such reports can then be used for representing the nature of crises events more formally so they can be processed automatically by computer systems.

Although multiple models and platform exist for representing and visualising the different stages involved during the representation of emergency events, the existing approaches tend to either focus on report representation or on the formal portrayal of emergency event. This means that the critical links between information sources, reports, situations and events may be lost in existing crisis models and they cannot be used efficiently by emergency management platforms.

In this paper we introduce a three-tier ontology called DoRES (*DOcument-Report-Event-Situation*) for representing the data collection of information about particular events and crises, their aggregation into reports and their formalisation into events and situations. The main idea behind our event representation is that the formalisation of events and associated resources directly comes from gathered information that is processed into reports.

We decide to develop our ontology[1] based on the analysis of existing data structures and datasets as well as stakeholders. In particular, we decide to base our model on the widely used Ushahidi crisis platform[2] and extend it so that it can be used for modelling a wide range of existing datasets.

Even though different methods exist for building ontologies and data models, we decide to rely on two different approaches for building our new ontology. First, we propose to partially follow the NeOn methodology (Suárez-Figueroa, Gómez-Pérez, and Fernandez - Lopez 2015), a comprehensive approach for specifying, developing and evaluating ontologies. Second, we propose to apply the qualitative and structural design approach (Burel 2016) for including non-ontological resources and user studies during the specification phase of the model.

Although the proposed model may be applied to different crises and scenarios, the model is focused on providing a relatively simple model that can be easily reused and extended for specific situations. This paper also focus on the theoretical evaluation of the model as it has not been yet applied to in real world situation. We aim to test the integration of our model in a crisis platform in future work.

DESIGN APPROACH AND METHODOLOGY

The development of the proposed model needs to follow a methodology in order to make sure that the DoRES model properly captures and apply design requirements.

The NeOn Modelling Approach

The NeOn methodology (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012) (Figure 1) is an approach for developing ontologies, identifying 9 different scenarios (i.e. design steps) that may arise when creating a new ontological model. As part of the creation of a new ontology, it is necessary to identify what scenarios apply to a particular development, as well as to create an Ontology Requirement Specification Document (ORSD) (Suárez-Figueroa, Gómez-Pérez, and Villazón-Terrazas 2009).

A few different methods exist for designing ontological models such as Methonlogy (Lopez et al. 1999), On-To-Knowledge (Staab et al. 2001), and DILIGENT (Vrandecic et al. 2005). However, we decide to focus on the NeOn approach since it helps the integration of existing models and the reuse of non-ontological models.

As displayed in Figure 1 The NeOn methodology is divided into the following 9 scenarios:

– Scenario 1: *Specification to Implementation.*
– Scenario 2: *Reusing and re-engineering non-ontological resources (NORs).*
– Scenario 3: *Reusing ontological resources.*
– Scenario 4: *Reusing and re-engineering ontological resources.*
– Scenario 5: *Reusing and merging ontological resources.*
– Scenario 6: *Reusing, merging and re-engineering ontological resources.*
– Scenario 7: *Reusing ontology design patterns.*
– Scenario 8: *Restructuring ontological resources.*
– Scenario 9: *Localizing ontological resources.*

For creating our crisis model, we have to follow the scenarios 1 and 9. To some extent we also try to reuse some commonly use ontologies as outlined in other scenarios. However, we do not strictly follow the ontology reuse scenario as it is not the focus of the DoRES data model.

The main scenario for developing the model is *Scenario 1*, as the DoRES ontological model needs to be developed from scratch. An important task of this scenario is the creation of an Ontology Requirement Specification Document (ORSD) (Suárez-Figueroa, Gómez-Pérez, and Villazón-Terrazas 2009) that describes the purpose, scope, implementation language, target group and intended uses of the specified model. In particular, this specification document needs to define a set of requirements that are defined as a set of Competency Questions (CQs). In order to create the ontology requirement specification, we need to collect knowledge from different sources and design competency questions.

[1]DoRES Ontology, `http://socsem.open.ac.uk/ontologies/dores`.
[2]Hushahidi Platform, `http://www.ushahidi.com`.

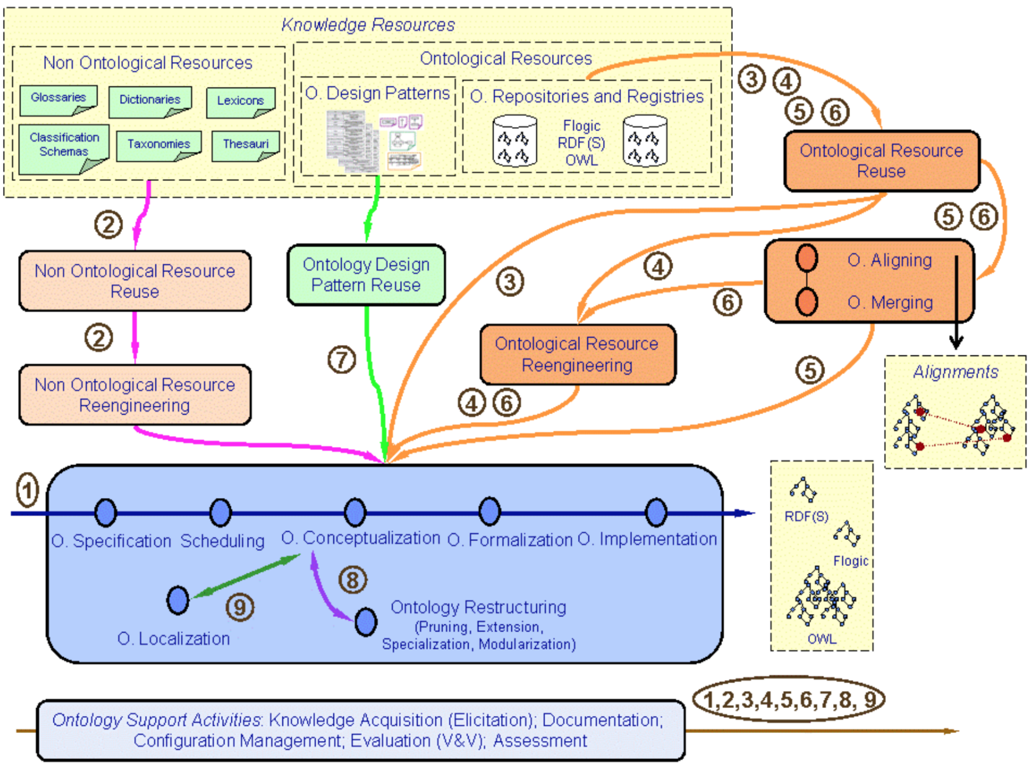

Figure 1. Scenarios for Building Ontology Networks (Image source: Suárez-Figueroa, Gómez-Pérez, and Fernandez - Lopez 2015).

Although the second scenario is in principle designed to help the integration of non-ontological data, it focuses on glossaries, dictionaries, lexicons, classification schemes and taxonomies, and thesauri. This type of resource is wildly different from the ones we are integrating when designing our model (i.e. highly structured data). As a result, the second scenario is not really suitable for our task.

For improving the usability of the model, we use scenario 9 which mostly consists of translating ontological labels and descriptions to multiple languages.

Although the scenarios 3, 4, 5, 6, 7 and 8 could be also applied to the design of the model we decide to only focus on the previous two scenarios. Nevertheless, when possible, we try to map some of the key DoRES concepts to existing ontologies that are not necessarily designed for representing crises (e.g. SIOC,[3] FOAF,[4] DC Terms[5]).

The Qualitative and Structural Design Methodology

One of the main shortcomings of the NeOn methodology is that the approach does not really consider existing data structures and datasets as part of the development process. Even though the second scenario proposes the integration of non-ontological resources, its focus is not on existing data structures but on non-practical knowledge (e.g. thesauri, dictionaries). Therefore, the NeOn approach is mostly suitable when: 1) the new ontology needs to represent or integrate completely new datasets; or 2) the new ontology needs to integrate with existing ontologies.

Although integrating existing ontologies can be seen as a type of structural analysis since it examines how existing ontological models can be used for a particular modelling task, it does not include a data format that is not already formally represented.

In this context we propose to integrate elements from the qualitative and structural design methodology (Burel 2016) where the design of a particular model is extracted from qualitative studies (e.g. interviews, surveys) and the structural analysis of datasets and the structure of existing software platforms or processes (e.g. thread structure of the data, user social interactions).

[3]SIOC, http://rdfs.org/sioc/spec.
[4]FOAF, http://xmlns.com/foaf/spec.
[5]DC Terms, http://dublincore.org/documents/dcmi-terms.

	Ontology Requirements Specification Document Template
1	**Purpose**
	"Software developers and ontology practitioners should include in this slot the purpose of the ontology"
2	**Scope**
	"Software developers and ontology practitioners should include in this slot the scope of the ontology"
3	**Level of Formality**
	"Software developers and ontology practitioners should include in this slot the level of formality of the ontology"
4	**Intended Users**
	"Software developers and ontology practitioners should include in this slot the intended users of the ontology"
5	**Intended Uses**
	"Software developers and ontology practitioners should include in this slot the intended uses of the ontology"
6	**Groups of Competency Questions**
	"Software developers and ontology practitioners should include in this slot the groups of competency questions and their answers, including priorities for each group"
7	**Pre-Glossary of Terms**
	Terms
	"Software developers and ontology practitioners should include in this slot the list of terms included in the CQs and their frequencies"
	Objects
	"Software developers and ontology practitioners should include in this slot a list of objects and their frequencies"

Figure 2. Template for creating an Ontology Requirement Specification Document (ORSD) (Image source: Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012).

In order to use this methodology, we need to: 1) obtain requirements and perceived needs by stakeholders using interviews or surveys (qualitative phase); and 2) collect the data that needs to be represented (e.g. Ushahidi data format, social media posts) (structural phase). Following that phase, we can generate competency questions based on the analysis of the interviews and the collected datasets.

Ontology Evaluation

Although the NeOn methodology proposes an approach for developing a requirements document, it does not offer a clear process for evaluating if the developed model fulfils the ontology requirements.

We evaluate the DoRES model by mapping competency questions to the classes, properties and relations of the developed ontological model and by verifying if there is a possible query that can be used for connecting the different ontological resources associated with a given competency question. Therefore, the evaluation is a three steps process: 1) we map the classes, relations and properties from the DoRES model to competency questions; 2) we determine if there is a path in the DoRES ontology that connect the classes, relations and properties extracted from the competency questions; 3) if each competency question can be mapped and connected successfully to the DoRES model, we conclude that the ontology successfully represent the competency questions.

ONTOLOGY REQUIREMENT SPECIFICATION

According to the first scenario of the NeOn methodology, the first step for creating a new ontological model from scratch is to create an Ontology Requirement Specification Document (ORSD) (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012). In order to do so, we need to collect different information.

As outlined in Figure 2, the ORSD document is divided in 7 different parts. For filling each of these parts, we use stakeholders' interviews, analyse the structure of the Ushahidi platform and different crises related datasets. We mostly follow the structure outlined by Figure 2 and use the qualitative and structural design approach for determining the requirements of the DoRES model.

Requirements Information Sources

As part of the ORSD design, we analyse three different type of data: 1) stakeholder interviews; 2) the Ushahidi platform data structure, and; 3) the structure of different crises datasets.

Stakeholder Interviews

Many requirements come directly from analysing the needs of existing communities dealing with emergency situations. In this context, 8 interviews were conducted in order to better understand the model requirements.

The interviews involved an ICT specialist for disaster management and 7 community leaders. Each interviewee was asked questions about how they currently use technologies when dealing with crises, and specifically *What sociotechnical requirements should be considered to design a social platform to boost communities' resilience in a disaster situation?*

From the different interviews we observed that there was a strong need for a platform and model that allows anonymous reports, privacy management, the collection of event location and reports as well as methods for searching particular events and the ability to assign tasks to reports.

Stakeholders need to create reports of incidents with geolocation, time and date, the source of the information (e.g. data source, person reporting the incident) while ensuring methods that allow anonymous reports and feedback. The reliability of information needs to be available, and reports need to be approved. It should also be possible to assign action to reports and check their status. Reports should be available in different languages if possible. Information should also be categorised (e.g. needs, resources). In term of data sources, the model should support means for adding multiple data sources such as social media (e.g. Twitter[6]) and SMS.

Besides the need for representing reports of event and external data, the interviews showed a strong need for identifying the reliability of information, privacy management as well as assigning tasks for solving particular issues. Therefore, the DoRES model needs to provide an easy representation for external data and for a task representation model, as well as access to management of information and its trustworthiness.

Ushahidi Data Structures

The different data structures used in the Ushahidi platform are direclty available on th Ushahidi website.[7]

By analysing the different APIs of the Ushahidi platform, we observe that the information associated with the Ushahidi platform data structures consists of either properties or relations. Properties are textual fields that are not shared across data structures, whereas relations are used for linking different data structures together.

In general, it can be observed that different input sources (Message) need to be integrated into the DoRES model, then converted into a standardised unit of information (Post). These posts are then categorised (Tag) or grouped (Collection). Users (User) need to be associated to documents as creators and input sources. Finally, users need roles (Role) that can be used for giving access permission to the platform data.

Crisis Related Datasets

Many of the available crisis-related datasets and data sources come from social media and particularly Twitter.

The following table (Table 1) lists the different crisis datasets that have been investigated in this paper. The available data can be divided depending on the data that was used for building a particular dataset. We distinguish three types of data source: social media data (i.e. Twitter posts), user reports (e.g. Ushahidi, ACLED[8]) and news agency data (e.g. news websites). Each data types have advantages and disadvantages. Social media data is widely available, however reliability is unclear and the format is highly unstructured. Citizen reports are more scarce but potentially more useful as they are formatted specifically for describing events. Finally, news data has the advantage to be more reliable. However, such data is more likely available after an event occurs and is low-level as it is summarizing a situation.

In term of data formats, existing social media datasets tend to be based on Twitter data, therefore, they directly follow the twitter message format and contains small short text with user information and sometimes user GPS coordinates that can be used for identifying the location of particular events.

Report data is platform-specific but generally contains a title, a date, a location, a description, and a type (e.g. fire, earthquake). Sometimes there can be additional information depending on the type of report. For example, the Ushahidi instance created for monitoring the USA presidential elections of 2016 has custom fields about candidates in each reports.

[6]Twitter, http://twitter.com.
[7]Ushahidi API, https://wiki.ushahidi.com/display/WIKI/Ushahidi+3.x+REST+API.
[8]ACLED, http://www.acleddata.com/data.

Table 1. Crisis related datasets

Dataset	Description	Media Type	Dataset Size
Crisis Lex T26	26 crises annotated with informativeness, information type and source.	Twitter (Social Media) ≃ 250k Tweets	
Incident Tweets	Data collected from multiple cities in the USA and UK.	Twitter (Social Media)	≃ 15M Tweets
Crisis Lex T6	6 Crises. Annotated by relatedness.	Twitter (Social Media)	≃ 60k Tweets
Crisis NLP	Multiples events datasets with some computed features.	Twitter (Social Media)	≃ 40M Tweets
Crisis Map (Ushahidi)	Many event report from Ushahidi deployments.	Citizen Reports (Ushahidi)	33 Events
Phoenix Data Project	Near real-time event dataset created by scrapping 400 news sources.	Event Summaries (News Agency Data Source)	Monthly datasets (expanding)
GDELT	Created in near real-time created from multiple data sources in different languages.	Event Summaries (News Agency Data Source).	Collected every 15 minutes (expanding)
ACLED	Event summaries created weekly about event occurring in Africa and Asia.	Event Summaries (Created and verified manually).	Weekly datasets (expanding)
Crisis Net	Data of crises such as diseases, political conflicts, and health.	Reports automatically generated from different data sources.	≃ 1.6M Items
Relief Web	Real-time API access to reports since 1996. P	Citizen Reports (Unformatted data).	≃ 54K Reports
HDX	A dataset repository that contains multiple datasets about different crises and related resources.	Citizen Reports / Event Summaries / Social Media.	4163 Datasets / 244 Locations / 804 Sources (expanding)

Finally, many of the news agency based datasets such as the GDELT, ACLED and Phoenix Data Project datasets follow the CAMEO (Schrodt and Yilmaz 2008) model that provides a taxonomy to identify the type of event mentioned as well as the actors involved.

The analysis of the crisis related datasets shows that the Ushahidi data structures already support many of the requirement of the analysed dataset except for the representation of domain specific information (e.g. Twitter posts) and rich user or event model that is mostly given by the CAMEO taxonomy and the Twitter data.

The Ontology Requirement Specification Document (ORSD)

Based on the analysis of the previous information sources, we can create the ORSD that can be used for specifying what the DoRES model should look like.

DoRES Aims and Model Purpose

The aim of the DoRES model is to create a model that can be used for representing information sources, reports as well as the events and situations that occurs in emergency crises.

The model needs to be general enough to cover a wide variety of scenarios and therefore be flexible as it needs to model multiple types of data sources. In the case of ontological development, a flexible model needs to offer relatively loose semantics (i.e. avoid overspecialisation) so that new types of users or resources do not require important ontological modifications.

In terms of scope, the model aims to support the modelling of crises by representing information sources, reports as well as events and situations.

Intended Use and Users

The DoRES model needs to satisfy different user groups such as governmental organizations and non-governmental groups, as well as individuals. Such individuals may have many different aims and goals. The model also needs to support algorithmic needs by allowing software to assert new information themselves (e.g. trustworthiness, extracted entities).

Following the interviews with stakeholders, we distinguish four different type of users for the DoRES model:

1. *Platform stakeholders:* The individuals or organisations that supply community platforms such as Ushahidi.
2. *Local community groups:* Community members of local activist groups.
3. *Responders:* Organisations and individuals that use information gathered by platforms in order to organise the response and recovery of a particular crisis.
4. *Individuals and small citizen groups:* Individuals or small communities that are affected by a particular crisis.

Competency Questions

A key part of the ORSD is to define competency questions that define what types of queries the model should be able to support.

We define competency questions as task-oriented questions that need to be satisfied by the DoRES model. These competency questions are used for making sure that the model supports all the question-based requirements and for validating the model against the competency questions. For example the need to have *geolocation* information associated with *events* can be modelled as the following question "*What is the location of an event?*".

Based on the interview analysis and the study of the Ushahidi and related dataset data structures, we create 102 different competency questions.

Term Glossary

Now that we have extracted a set of competency questions, we can extract the terms that are the most used in the questions in order to help the development of the model. The idea is that the most frequent terms are key aspects of the model and need to be modelled prominently (e.g. classes), whereas infrequent term may not need to be represented as prominently in the final model.

The NeOn methodology (Pérez et al. 2008) distinguishes three different types of terms: 1) competency question terms; 2) competency question answer terms, and; 3) object terms. The competency question terms are the top words that appears in competency questions, whereas answer terms are the ones that appears in the answer of the

Table 2. Top Terms Extracted from the Competency Question, Crisis Related Dataset and the Ushahidi Data Structures.

Type	Term (Frequency)
Competency Question	Document (27), Event (17), User (13), created (10), Type (9), Information (8), Message (8), Collection (7), Category (6), Platform (6), Actor (6), Media (6), updated (6), associated (5), related (4), Role (4), Report (4), name (3), description (3), Source (3), language (3), Account (3), Events (3), reliable (3).
Data Structures	created (13), allowed_privileges (11), id (10), URL (10), Form (9), data (9), User (8), Type (8), updated (7), Post (6), Message (6), Media (6), Event (5), Creator (4), Posts (4), description (4), sources (4), Collection (4), Crises (4), social (4), contact (4), name (3), annotated (3).

competency questions. The object terms are the named entities that are extracted from competency questions and answers.

Since we do not have competency questions that both contain data specific questions and answers, we generate the glossary terms as follow: 1) we extract the most frequent terms appearing in our competency questions; 2) we extract the most frequent terms appearing in the data structures that we have used for creating our competency questions. The idea is that besides the terms extracted from the competency questions, the property descriptions and names of the different datasets and the Ushahidi can help the identification of the key concept and attributes of the DoRES model.

The top terms extracted from the competency questions are listed in Table 2.

MODEL IMPLEMENTATION

Many of the datasets and data structure analysed when creating the ORSD are centred on reports and the ingestion of external documents rather than the direct modelling of events.

Reports can be used in different ways for documenting events, needs, resources and so on and form the base of the DoRES model. The advantage of using a report centred approach is that it allows a more organic gathering of information related to events without needing rigid data structures. This is particularly suitable for resilience platforms that are deployed in large variety of situations where the types of reports are context specific.

We use a situation model for documenting how events affect their environment. Typically, a situation would involve different entities (e.g. local population, building, political situation) and would define the state that was induced by the situation. For example, a building explosion (situation) would induce a particular building (entity) to be collapsed (status).

Another important component of the model is the representation of categories and collections. We distinguish collections from categories as manually user curated groups of documents and reports whereas categories are hierarchical organisation used for classifying reports and events.

For representing users and the permissions associated documents, reports and other model classes we use the concepts of roles and accounts where user hold roles that are associated with user permissions. We also use the concept of user account that are used for holding platform specific user information such as the user contribution reliability.

Finally, we add a simple model for representing tasks that can be attached to reports and assigned to users. In the following sections, we refer to the DoRes namespace[9] as `dores` in the following sections.

Classes and Relations

The DoRES model is divided in different classes that separate crisis related data in four different types of information (reports, documents event and situation) and associate them with tasks as well as users. Figure 3 shows the different classes and relations of the DoRES model.

[9]DoRES Namespace, http://socsem.open.ac.uk/ontologies/dores.

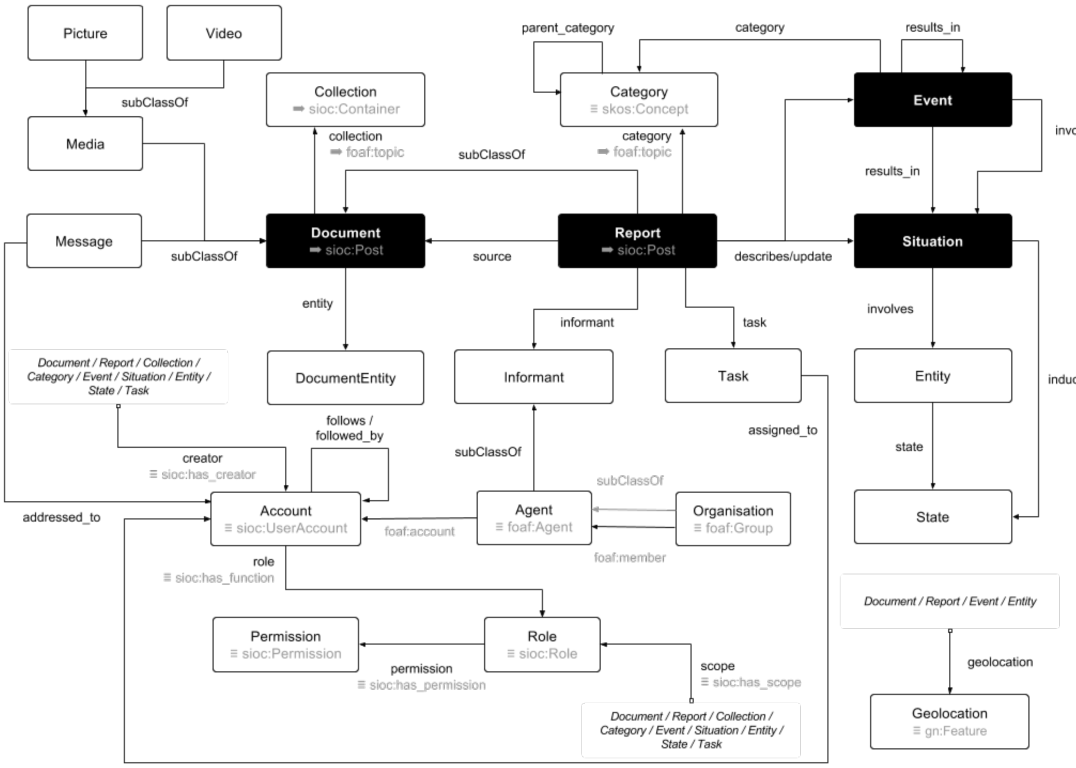

Figure 3. The DoRES Ontology classes and relations.

Information Sources, Reports and Situations

The competency questions show that many properties and relations are focused on different types of documents and that both the Ushahidi platform and the crisis related dataset models prefer modelling event indirectly using user submitted reports or automatically generated documents. As a consequence, we decide to centre the representation crisis related information around the concepts of `dores:Report`, `dores:Situation`, `dores:Event`, `dores:Document` and `dores:Informant`.

In order to connect each of these components, we decided to associate a `dores:Report` to a `dores:Document` that represent the information sources that were used for creating a report such as an external media (`dores:Media`) or message (`dores:Message`). These classes can be subclassed as needed if a new `dores:Document` representation is necessary. A `dores:Report` can be also linked to a `dores:Informant` that can be an `dores:Agent` or `dores:Organisation` and used for representing the organisation or person that gave the information used in a `dores:Report`.

We extend messages (`dores:Message`) from documents (`dores:Document`) as contrary to documents, messages occur in conversations (e.g. Twitter messages, forum posts) whereas documents are standalone information pieces (e.g. news articles, blog posts).

Besides associating reports to documents and informants, reports are also connected with the events (`dores:Event`) and situations (`dores:Situation`) that they are describing or updating. Events are things that happens or takes place whereas situations are used for representing the states (`dores:State`) of entities (`dores:Entities`).

The separation between `dores:Document` and `dores:Informant` with `dores:Event` and `dores:Situation` is designed for identifying how a piece of information obtained from an external source is integrated and processed through a report (`dores:Report`) into a piece of usable knowledge in the form of a situation (`dores:Situation`) or event (`dores:Event`). This allows the model to be queried from different perspectives. For instance, `dores:Document` can be used for understanding where an information comes from whereas `dores:Report` can be used for understanding how a `dores:Document` was brought in the DoRES platform and, finally, `dores:Event` and `dores:Situation` can be used for analysing current emergency situations by observing the `dores:State` of an `dores:Entity`.

Besides `dores:Document` and `dores:Message`, `dores:Report` can be also associated with different type of medias (`dores:Media`) such as pictures (`dores:Picture`) and videos (`dores:Video`).

Collections, Categories and Topics

The different type of information collected by the DoRES model can be grouped and categorised in different ways. For instance, `dores:Report` and `dores:Document` can be grouped into `dores:Collection` whereas `dores:Report` and `dores:Event` can be grouped in come:Category.

Collections (`dores:Collection`) are directly designed to emulate the Ushahidi document collection by allowing different types of information to be grouped together as a list according to arbitrary criteria while categories (`dores:Category`) are used as a public hierarchical classification model for information retrieval purpose.

Another important part of the model is the representation of the actors, organisations and the accounts that are used for representing the creator of `dores:Document` and the person that posted a `dores:Report` as well as the people and organisation that created a `dores:Situation` or `dores:Event`.

We distinguish different types of users. In particular, we define `dores:Agent` as a generic type of user and the `dores:Organisation` class that can be used for defining different types of organisations or group a user can belongs to. For instance, a user could belong to a particular NGO or religious group.

Users (`dores:Agent`) are all defined as a subclass of `dores:Informant` that can be used as the information source of `dores:Report` when no document source (`dores:Document`) is available but when an information comes from a known individual or person.

For contributions within the DoRES model, the `dores:Accout` class is used for abstracting contributor specific information that only exist within the DoRES model such as the number of documents created by a `dores:Agent`.

Tasks, Roles and Permissions

As highlighted by the ORSD, the DoRES model needs to support access permissions to the different content represented by the model. In this context, we define the class `dores:Role` and `dores:Permission` that are used together for associating permissions to multiple model classes.

The Ushahidi platform also supports the assignment of tasks to platform users. We support tasks by adding the `dores:Task` to the model and linking it to `dores:Account` and `dores:Report` so that reports can be used for assigning tasks.

Properties

Contrary to relations, properties are not associated with other classes of the DoRES ontology. The 58 properties required for each classes can be directly extracted from the competency questions as well as the previously analysed data structures. Due to lack of space we do not describe the properties in this paper. However, each property is described in the ontology description that can be accessed by accessing the ontology namespace.

It is important to note that the reliability of the different elements of the ontology are not represented as properties. Instead, the reliability and trustworthiness of resources is represented using the Veracity ontology (Burel et al. 2010).

Integration with Existing Ontologies

As displayed in Figure 3, the DoRES model reuse multiple ontologies for modelling the different classes, properties and relations discussed in the previous section.

Crisis Related Ontologies

Although many ontologies have been designed for representing crises or related information, most of them do not focus on the concepts of report and document. Rather than using those concepts, existing models prefer focusing on the event representation of emergency crises and ignore the collection of evidences and user submitted reports as a mean for representing event related information. Task representation is also generally absent from crisis related ontologies.

The proposed three-tier design allows the model to be integrated in typical digital emergency platforms workflows by fully supporting the collection, analysis and formalisation of input data. For instance, a particular information can be uploaded on a platform by an individual (`dores:Post`), then analysed by an NGO (`dores:Report`) and then formalised (`dores:Event/dores:Report`) so that it can be queried and visualised effectively (e.g. visualisation of a situation evolution, identification of available and unavailable resources). Existing models prefer to focus on only one or two of these aspects whereas the DoRES ontology provide a complete end-to-end model that can be integrated and enhance existing crisis platform workflows.

Many ontologies have been designed for modelling event in crises situations such as MOAC (Management of a Crisis)[10] and HXL (Humanitarian eXchange Language). However, despite modelling resources, processes, damages, and disasters (fire, people trapped, medical emergency), these models do not provide representations for documents and reports. The need for more complete models was highlighted by Liu et al. (Liu et al. 2013). Moreover, existing semantic models were mostly designed for providing a static view of emergency situation, where elements are captured but not their temporal evolution. Non-ontological models have been also developed such as the Disaster Management Metamodel (Othman and Beydoun 2013) and the Crisis Metamodel (Bénaben et al. 2008) that both provide frameworks for modelling situations, tasks and resources in a crisis. However as with the previously mentioned models they tend to ignore the data collection and the reporting phases that are modelled in the DoRES ontology.

In term of document representation, the CURIO ontology[11] (Collaborative User Resource Interaction Ontology) provides means for representing the collection of documents in an emergency context. However, the model only provides a simple model of event without the concept of event situations. However, the CURIO ontology shares some similarities with the DoRES model as it is reusing many concepts from the SIOC ontology (Breslin and Decker 2006).

Other Ontologies

Most of the ontologies reused in the DoRES ontology are based on widely used ontologies. The main reason for reusing such kind of ontologies is that it improves the usability of the model by allowing it to be used similarly to existing ontologies.

The DoRES ontology reuses five different ontologies for modelling its components and properties. The main ontology reused for representing the different elements of the DoRES model is the SIOC ontology (Breslin and Decker 2006) that provides constructs for representing online communities. We reuse the SIOC ontology for representing documents, reports, collections, permissions and roles as well as a different properties and relations of the model.

We also reuse the FOAF (Friend Of A Friend) ontology for representing users in the model as it integrates well with SIOC and provides ways for representing agents and organisations.

For modelling geolocation, we use the Geonames[12] and WGS84[13] ontologies as they provide basic representations of geolocation coordinates that can be used for identifying the location of events and other resources.

The Dublin Core model is also used as it provides many properties, relation and classes specifically designed for modelling documents. Finally, for representing the trustworthiness of the different content of the platform we us the Veracity ontology[14] (Burel et al. 2010) as it provides methods for asserting the reliability of different resources.

MODEL VALIDATION

In order to evaluate the DoRES ontology, we first extract the key classes, properties and relations associated with each competency questions. Then, we check if a path exists between each element of the extracted properties, relations and classes. Finally, we assert if a competency question is validated based on the path existence.

For each competency question, we list the classes and relations that needs to be connected and evaluate if the competency question is validated (i.e. if there is a path between the classes, relations and properties associated with the competency question).

For instance the "*What is the location of an event?*" competency question can be mapped into DoRES as the following: `dores:Event` → `dores:geolocation` → `dores:Geolocation`.

All the competency questions are successfully represented by the model. However, it is important to note that some mappings are not directly mapped by the DoRES ontology but are inferred through merged ontologies. For instance, the topic of `dores:Message` is not modelled directly by the DoRES model but can be represented through the `sioc:topic` relation.

[10]MOAC, http://www.observedchange.com/moac/ns.
[11]CURIO, http://purl.org/net/curio/ns.
[12]Geonames Ontology, http://www.geonames.org/ontology.
[13]WGS84 Ontology, https://www.w3.org/2003/01/geo/#vocabulary.
[14]Veracity Ontology, http://purl.org/net/veracity/ns.

CONCLUSIONS

We introduced the DoRES ontology as a model that helps the representation of events and related information during emergency crises. We based the development of the model on the NeOn methodology (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012) and on a qualitative and structural design approach (Burel 2016) and evaluated the DoRES ontology by mapping competency questions to ontology properties, relations and classes.

After creating an Ontology Requirement Specification Document (ORSD) (Pérez et al. 2008), we implemented the model using semantic web technologies (RDF/OWL) and tried to link the newly developed data structures to existing ontologies such as FOAF and SIOC.

We validated the DoRES ontology by mapping competency questions to the DoRES ontology properties, relations and classes.

In future work, we plan to apply our model to real world crisis situations to see how it behaves in the field by integrating it into a community resilience platform. We also aim to develop domain knowledge that can be used with the DoRES ontology.

ACKNOWLEDGEMENT

This work has received support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687847 (COMRADES).

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Attributes for Simulating Spontaneous On-Site Volunteers

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ABSTRACT

Disaster managers report that several disasters would have turned out on a dramatic scale without spontaneous unaffiliated on-site volunteers (SUV). Since SUVs are usually not integrated in chains of command and behave in a certain pattern of its own, coordination of SUVs becomes a challenge for disaster management. One key to coordination is communication and adequate support by information systems. However, real disasters or field tests are usually too expensive, elaborate, and partly impossible when coordination of SUVs is to be exercised or novel tools and methods must be evaluated. Simulating the SUV's behavior by software-agents is considered a constructive solution, however, the specification of simulation settings is an open research field. Therefore, this paper aims at identifying relevant attributes affecting SUVs behavior by a state-of-the-art literature review, classifying and discussing the attributes. Our results provide a sound basis for defining SUV-agents and performing suitable simulations in the future.

Keywords

spontaneous volunteers, disaster management, simulation, coordination, software agents

INTRODUCTION

Recent years have shown an increasing number of natural and man-made disasters worldwide (Dressler et al., 2016). Governmental disaster relief is usually supported by humanitarian organizations (Geißler, 2014). However, demographic as well as sociological changes lead to massive membership declines in humanitarian organizations (Hofmann et al., 2014; Geißler, 2014) changing the relevance of so-called spontaneous unaffiliated on-site volunteers (SUV). Integrating SUVs in disaster management may at least partly balance emerging personnel deficits (Hofmann et al., 2014) and disaster managers as well as practitioner's report that several disasters would have turned out on a dramatic scale without the help of SUVs (Detjen et al, 2015; Geißler, 2014).

Along with the human desire to help, actual options for communication play a critical role during disasters and for managing disaster response: social media and mobile devices dramatically changed the way how citizens perceive disasters by enabling new potentials in information, cooperation, and coordination (Büscher et al., 2014). Beyond the undoubtedly positive aspects (see, e.g., Ludwig et al. 2015, Schweer et al., 2014), SUVs have also caused harm or put themselves into dangerous situations. According to reports, SUVs barely had information about requirements at operating sites and searched for places to help on their own based on subjective or even false information, mainly gained from social networks (Hofmann et al., 2014). Such self-organization does usually not support coordination goals of official disaster managers, in fact, it led to overloads of operating sites impeding officials to work properly (Fernandez, 2007) and to critical shortage on other operating sites mainly in the periphery.

Without doubt, SUVs mean a valuable resource in disaster response. However, this resource should be properly coordinated so that the provided potential is not wasted, the official on-site forces are not set back, and the helpers are not put into danger. Avoiding such nonproductive “help” and providing innovative methods and applications for an effective coordination of SUVs reveal a challenging field of research for IT supported disaster management.

A central key to coordination of SUVs is planning and communication: disasters are dynamic processes requiring the coordination of many logical and physical entities (Simpson, 2014; Aslam et al., 2010) like disaster relief forces, affected people, or even SUVs. While planning and preparation may massively decrease disaster scales in general (Wagner and Agrawal, 2014), integrating SUV in this complex context necessitates adequate methods and solutions for increasing the coordination of SUVs and for predicting the SUV’s behavior.

To address this key issues, several disasters in the last decade have led to intensive support of research. In Germany, e.g., several projects like KUBAS, REBEKA, and others are funded by the government focusing on the effective assignment of SUVs in disaster management (BMBF, 2017). Scientific communities, conferences like ISCRAM, or special tracks/issues on general information systems conferences/journals are fostering research in this area. One main challenge for all research effort is the testing and validation of new approaches as well as the proof of concept, e.g., in practitioners’ drill. Thus, new approaches are usually evaluated through field experiments. However, field experiments with many SUVs require a large amount of participants, may have durations of some days, and take place on a few locations at the same time. Therefore, such experiments are expensive, elaborate, and partly impossible to conduct (Sautter et al., 2015; Takahashi, 2007; Balasubramanian et al., 2006). Whenever field experiments are not realistic, computer simulation is a common approach to test, evaluate, and optimize real world scenarios and approaches with a minimal effort (Arai and Sang, 2012). Up to now, to our knowledge, simulation of SUV’s behavior with respect to cooperation and communication has not yet been part of any research. Agent-based simulations seem to be a sound approach to simulate SUV’s behavior in disasters, because it has already been proven to be a proper way to simulate human and social behavior as well as simulating many entities (Wagner and Agrawal, 2014; Mas et al., 2012; Pan et al., 2007; Takahashi, 2007).

With a comprehensive simulation of SUV’s behavior in mind, developing software agents first requires the analysis of the real-world behavior and all behavior impacting attributes (Macal and North, 2007). Therefore, the goal of this contribution is the identification of crucial attributes representing and influencing SUV’s behavior with respect to their cooperation behavior. This is achieved by conducting a broad literature research including also research from technical science and psychological publications. Based on the identified state-of-the-art, the description and analysis of interdependencies between different attributes is also part of our research and obligatory to provide a valid insight. Following the software-agent’s definition by Lind (Lind, 2001), the identified attributes are finally classified to provide a sound basis for developing software-agents and a realistic multi-agent simulation environment for future testing, evaluating, and optimizing volunteer-based research approaches. The following part provides a methodological and comprehensible description of our literature review resulting in the state-of-the-art. Afterwards, the identified attributes are discussed describing the behavior of volunteers and their interrelations. Subsequently, the identified attributes are categorized with respect to specifying software-agents and multi-agent simulation environments. A conclusion with outlook on further research is given in the final part.

RELATED WORK: BEHAVIOR OF SPONTANEOUS VOLUNTEERS IN DISASTER-RELATED RESEARCH

The literature review aims at covering relevant aspects simulating, describing, and attributing SUVs and their behavior. Since research discusses SUVs from various perspectives, the body for our literature was selected in a broad range, e.g. from IT-related, sociological, and psychological research. In a first iteration scientific papers as well as practice reports were identified by a tag word search. The relevant tag words are represented in Table 1 containing all words that lead to a broad overview. The tag words were combined in a logical manner. Although SUVs have been part of international research for years, the relevance of the topic increased at least in Germany after the flooding’s 2013. Thus, an additional search for literature and reports in German was performed in a second round. Furthermore, the literature review not only contains scientific papers but also practice and experience reports of official forces, disaster managers, and SUVs themselves. Therefore, for a comprehensive search, scientific databases (ScienceDirect, AISeL, EBSCO) as well as a Google search and Google Scholar were used. Last but not least, the selected literature was supplemented by a backward search on relevant references.

Table 1. Tag Words for Literature Review

German	English
freiwilliger Helfer	volunteer
Katastrophe	disaster, catastrophe
Krise	crisis
Motivation	motivation
Großschadensereignis	major incident
(Helfer-)Attribute	attributes
(Helfer-)Parameter	parameter
Katastrophenhilfe	disaster relief
ungebundene Helfer	spontaneous volunteer
Schadenslage	*- no translation available -*
Erfahrungen	experience
Erfahrungsbericht	report
Simulation	simulation

As a first result of the literature review, recent research approaches propose agent-based simulations as a common and appropriate way to simulate human behavior (Takahashi, 2007). Computer simulation and especially agent-based simulation, is, thus, an integral component of disaster research (Coates et al., 2011; Gonzalez, 2009). The literature review revealed several methods and tools supporting agent-based simulation whereas most of them focus on evacuation scenarios: by simulating individual vehicles, Chen and Zhan used multi agent simulation to evaluate evacuation impacts on traffic flows from disaster areas (Chen and Zhan, 2008). Wagner and Agrawal investigated evacuation scenarios for concert venues, whereby the concert-goer were simulated as agents (Wagner and Agrawal, 2014). The Great East Japan Tsunami in 2011 motivated researchers to simulate the evacuation behavior of pedestrians and car drivers in a tsunami scenario (Mas et al., 2012). Since recent human and social behavioral data of emergency evacuations rely on assumptions that may be unrealistic or inconsistent, Pan et al. developed a multi agent-based framework for simulating human and social behavior during emergency evacuations (Pan et al., 2007). Furthermore, Arai and Sang provided a multi agent-based model for simulating the rescue of disabled people with the help of volunteers (Arai and Sang, 2012). All these studies use software agents to simulate various entities in disasters from different views. Thus, the literature review revealed that agent-based simulation has already been applied for evaluating disaster-related approaches and for observing disaster-related behavior with respect to the movement of people. Nevertheless, none of the related work applied simulation for the cooperation and/or communication behavior of SUVs in the disaster context.

However, outside of the agent-based simulation focus, several researchers have analyzed how SUVs interact, cooperate, and communicate especially via social networks (e.g. Peary et al., 2012; Starbird and Palen, 2011). Peary et al. discus the potential to utilize social media in disaster preparedness and response by analyzing social media after the 2011 East Japan earthquake when volunteers as well as affected people reported and shared a lot of information (Peary et al. 2012). Likewise, Starbird and Palen analyzed volunteers operating via social media. They described the role of so-called digital volunteers by analyzing Twitter posts during the Haiti earthquake in 2010 (Starbird and Palen, 2011). Furthermore, other scientists have provided research approaches and applications to improve communication or coordination of SUVs (e.g. Reuter et al., 2015; Hofmann et al., 2014). Based on recent research outcomes, Reuter et al. presented a cross-social-media application allowing information to be acquired and distributed cross-media and cross-channel for moderating emerging groups of SUVs as well as for structuring information (Reuter et al., 2015). Hofmann et al. presented an app-based system to support disaster managers in coordinating SUVs (Hofmann et al., 2014).

Taking the identified approaches related to volunteers in the context of disaster management into account, a main outcome of the literature review is that recent research mainly has focused on so-called digital volunteers collecting and sharing information via social networks (Kaufhold and Reuter, 2014). Such digital volunteers do not physically help at operating sites but exclusively on the internet. In contrast, the types of physically present volunteers helping and supporting official forces on-site is not in the focus of current research. Furthermore, none of the related research outcomes neither cover, identify, nor discuss relevant attributes influencing the behavior of SUVs.

IDENTIFYING RELEVANT ATTRIBUTES DESCRIBING THE BEHAVIOR OF SUVS

For identifying relevant attributes influencing the behavior and the coordination of SUVs in disaster context, the identified literature body was analyzed again. Since digital volunteers and on-site volunteers are different with respect to their motivation, support, and activities, the following analysis and discussion is focused solely on SUVs who are not professional or voluntary working for humanitarian organizations. SUVs are defined in the following as private persons who are not trained in disaster management and want to help spontaneously after the occurrence of a disaster. They want to support official forces on-site with their physical presence and help. With this type of SUVs in mind, the identified literature body has been analyzed in more detail. Relevant attributes influencing the behavior of SUVs and their coordination were identified by a descriptive exploration following a set of guiding questions presented in Table 2.

Table 2. Guiding Questions for Volunteer Attribution

Who helps spontaneously in disasters?
Why does somebody help in disasters?
What do SUVs do?
When and how long do SUVs help?
Where do SUVs help?
What else features SUVs?

Answering those guiding questions led to a structured identification of relevant attributes which will be explained in more detail in the next part. Overall 25 attributes (A1 – A25) affecting and featuring the coordination behavior of SUVs during disasters were identified. An overview of the attributes and their discussion within the literature are represented in Table 3. A parametrization of the identified attributes or their modeling within software agents were also in the focus of our detailed literature analysis. However, without disclosing a secret, the results show that for nearly all attributes the parametrization and modeling remain subject of further research.

A1: Age. Observations of the flooding 2013 in Germany show that people of all ages, genders and classes were involved in the disaster coverage (Geißler, 2014). Already in 1991, Wenger identified primarily males between 18 and 45 years with higher education as SUVs (Wenger, 1991). However, further observations controvert this assumption outlining that social economic factors and especially age have no influence on spontaneous volunteering (e.g., Auferbauer, 2016). Summing up, an age-based influence on spontaneous volunteering seems not to exists (Auferbauer, 2016; Points of Light Foundation, 2005; Lowe and Fothergill, 2003) or is, at least, not definitely proven. One reason for the ambivalent results is seen in a lacking registration of SUVs in the data of analysed disaster response scenarios (Schweer et al., 2014). Although the influence of age on spontaneous volunteering is not clear, it should be considered as relevant attribute, since it has clear interrelations with other identified attributes like capabilities or time aspects.

A2: Group Affiliation. In 2013, SUVs were primarily students being flexible in choosing assistance intervals (Zisgen et al., 2014; Geißler, 2014; Ebert, 2013). Furthermore, student classes, clubs, religious groups, or employees were exempted for helping (ARC, 2010). Group affiliation in general positively influences the pro social behaviour of the volunteers and, thus, the motivation to help (McDonald et al., 2015; Reuter et al., 2013; Barraket et al., 2013). Being part of a group or a society also increases the motivation to help (Barraket et al., 2013; FEMA, 2013). Therefore, group affiliation is seen as a relevant attribute influencing SUV's behaviour.

A3: Motivation. Motivation is generally described as trigger to participate in disasters (Australian Government, 2015). Furthermore, motivation is the basis to help and can be increased or decreased by other attributes. Many definitions for motivation exist especially from a sociologic view (Geißler, 2014; Falasca and Zobel, 2009). Summing up, individual human motivation is complex and not deterministic, thus, it cannot be completely simulated. However, motivation as the trigger for involvement in disaster coverage and voluntary help is a relevant attribute influencing SUV's behaviour that requires a deeper research before it can be adequately operationalized within software agents.

Table 3. Attributes of SUVs

Number	Attribute	Literature
A1	Age	Auferbauer, 2016; Geißler, 2014; Points of Light Foundation, 2005; Lowe and Fothergill, 2003; Wenger, 1991
A2	Group Affiliation	McDonald et al., 2015; Zisgen et al., 2014; Geißler, 2014; Reuter et al., 2013; Ebert, 2013; Barraket et al., 2013; FEMA, 2013; ARC, 2010
A3	Motivation	Australian Government, 2015; Geißler, 2014; Falasca and Zobel, 2009
A4	Concern	McDonald et al., 2015; Kaufhold and Reuter, 2015; Kircher, 2014; Barraket et al., 2013
A5	Information Channel	McDonald et al., 2015; Reuter et al., 2013
A6	Personal Connections	McDonald et al., 2015; Schweer et al., 2014; Barraket et al., 2013
A7	Social Networks	McDonald et al., 2015; Rizza and Pereira, 2014; Reuter et al., 2013; Barraket et al., 2013
A8	Perception	Kircher, 2014; Büscher et al., 2014; Geißler, 2014; Reuter et al., 2013
A9	Kind of Disaster	ARC, 2010; Fernandez, 2007; Paton, 1996
A10	Weather	Geißler, 2014; Kircher, 2014
A11	Experience	Australian Government, 2015; Geißler, 2014; Barraket et al., 2013; Lowe and Fothergill, 2003; Barraket et al., 2013
A12	Time of Day	BBK, 2014; Geißler, 2014; Paton, 1996
A13	Supporting Tasks	Geißler, 2014; Fernandez, 2007
A14	Task Preference	Schmidt et al., 2016; Kircher, 2014; Falasca and Zobel, 2009
A15	Capabilities	Hofmann et al., 2014; Kircher, 2014; FEMA, 2013; Points of Light Foundation, 2005
A16	Resources	Detjen et al., 2015; Kaufhold and Reuter, 2014
A17	Working Time	Geißler, 2014; ARC, 2010
A18	Time Preference	Geißler, 2014; ARC, 2010
A19	Working Duration	Geißler, 2014; Barraket et al., 2013; Points of Light Foundation, 2005
A20	Operating Site	Detjen et al., 2015; Hofmann et al., 2014; Luqmann and Griss, 2011
A21	Kind of Information	Lange and Gusy, 2015; Kaufhold and Reuter, 2015; St. Denis et al., 2014; BBK, 2014
A22	Location	Auferbauer et al., 2016; McDonald et al., 2015; Luqman and Griss, 2011
A23	Operating Site Preference	Auferbauer et al., 2016; McDonald et al., 2015; Luqman and Griss, 2011; CNCS, 2011
A24	Travelling	Kircher, 2014; Fernandez, 2007
A25	Randomness	Geißler, 2014;

A4: Concern. One leading aspect on spontaneous volunteering is emotional reactions to a disaster that reveal in concerns (Barraket et al., 2013). Concerns are not only emotional reactions to a disaster, they also originate from being directly affected by a disaster or when family members, friends, or somebody within the social network are affected (Kaufhold and Reuter, 2015; Kircher, 2014; Barraket et al., 2013). Concerns can be triggered or enhanced by media and especially social media bringing on-site information to people worldwide what may lead to concerns (McDonald et al., 2015). Concern, thus, is seen as a relevant attribute influencing a SUV's behaviour that also requires further research.

A5: Information Channel. Different media target different groups of people. SUVs are rather willing to help if they read Facebook posts of their friends being already involved in disaster response than watching people on mass media like television (McDonald et al., 2015; Reuter et al., 2013). Furthermore, the information channel is important for targeting different ages and groups of volunteers. In Germany, 70% of the 14-29-year-old are on Facebook while only 7% of the 70+ are (Statista, 2016). Students were the largest and most flexible group of volunteers during the flooding's 2013 in Germany (e.g., Zisgen et al., 2014), thus, information channel is seen as relevant attribute for targeting different groups.

A6: Personal Connections. As touched on concerns (A4), help requests from friends or relatives increase the motivation to help (Schweer et al., 2014; Barraket et al., 2013). Furthermore, a motivated volunteer typically activates more friends resulting in a phenomena known as "snow-ball-effect" that can massively increase the amount of SUVs in disaster relief (McDonald et al., 2015). Personal connections are further relevant attributes, since SUVs start helping within their close social network (Schweer et al., 2014) and extend it to other areas when the risk for family, neighbours, or friends is reduced to a minimum.

A7: Social Networks. People with a pronounced social network are rather supportive and willing to help much longer than people with a less pronounced social network (McDonald et al., 2015; Rizza and Pereira, 2014; Reuter et al., 2013; Barraket et al., 2013). This holds usually for both real and virtual social networks and, thus, is seen as a relevant attribute influencing a SUV's behaviour.

A8: Perception. Perceiving a situation as emergency or disaster is requirement for spontaneous volunteering (Geißler, 2014; Reuter et al., 2013). However, perception of a situation can differ between persons (Geißler, 2014) and may be influenced by media reporting (Kircher, 2014; Büscher et al., 2014). Therefore, perception is seen as a relevant attribute that should be operationalized within a software agent simulating SUV's behaviour.

A9: Kind of Disaster. Different kinds of disasters influence the motivation in various forms (Fernandez, 2007; Paton, 1996). The individual need to help is influenced by the size and scale of the disaster: the more dramatic a disaster is in scale the stronger is the individual will to help (ARC, 2010; Fernandez, 2007).

A10: Weather. In 2013, media reported that the flooding in Germany partly had event-character with musical support at the operating sites combined with good weather (Geißler, 2014). Officials and volunteers reported an increasing number of volunteers because of the summery temperatures (Kircher, 2014) and doubts exist whether the observed support would have been so extensive in case of cold and rain (Geißler, 2014). Although some researchers and practitioners see weather as a crucial factor, research results regarding the influence of weather on SUV's participation is not consistent. Thus, the influence of weather requires further research for adequately operationalizing it within software agents.

A11: Experience. Researchers found that volunteers are rather motivated for helping when they have made positive experiences in prior disasters (Geißler, 2014; Barraket et al., 2013). Principally, experience is not necessary for spontaneous volunteering (Lowe and Fothergrill, 2003), but it clearly influences the individual motivation to support (Australian Government, 2015; Barraket et al., 2013). Experience can be distinguished in those made in prior disasters and those made during current disaster relief. Since both influence the individual motivation, experience should be taken into consideration as relevant attribute.

A12: Time of Day. Research results suggest that the willingness to help is independent of the time of day (Geißler, 2014). However, other research and practitioners report from operating sites massively understaffed in the night (BBK, 2014; Paton, 1996). The influence of the time of day may be obvious and, thus, is seen as relevant attribute for simulating SUVs behaviour. However, its concrete influence requires further research.

A13: Supporting Tasks. During disasters, SUVs do various tasks that support victims and officials reducing disaster scale. In general, their supporting tasks do not require a special qualification (Geißler, 2014; Fernandez, 2007). However, it is obvious that not all SUVs are able or willing to support all kind of tasks (see A14), thus, supporting task is seen as a further relevant attribute.

A14: Task Preference. While tasks differ from disaster to disaster, SUVs have more or less clear preferences and ideas how and where to help. Neglecting such preferences may lead into bad experiences and frustration causing demotivation and negative motivation for further disaster assistance (Schmidt et al., 2016; Kircher, 2014; Falasca and Zobel, 2009). Thus, task preferences are a relevant attribute for modelling SUV's behaviour.

A15: Capabilities. Supporting tasks and task preferences may be influenced by individual capabilities like physical capabilities or the ability to be led by official forces (Hofmann et al., 2014; Kircher, 2014; FEMA, 2013;

Points of Light Foundation, 2005). Thus, capabilities are an important attribute to determine the kind of support that can actually be realized by a SUV.

A16: Resources. Recent disasters showed that SUVs are also providing resources like bottles for water, shovels, food, or occasionally heavy machines. These resources can be valuable for reducing disaster scales, because they cannot entirely be provided by officials (Detjen et al., 2015; Kaufhold and Reuter, 2014).

A17: Working Time. Working time per day of SUVs is reported to be related to their capabilities and mainly lying between 4 to 8 hours (ARC, 2010). Beside these findings, there are reports that at least students are willing to work much longer (Geißler, 2014).

A18: Time Preference. Although students (and other groups) are timely flexible to assist during a disaster, they have individual preferences over their time (Geißler, 2014; ARC, 2010). Time preferences also include time slots made available through work (ARC; 2010). Coordinating, planning and scheduling SUVs requires to take such preferences into consideration.

A19: Working Duration. On a general scale, supporting tasks usually end automatically for SUVs if and only if the help is no more needed (Geißler, 2014). Depending on the kind of disaster and individual time preferences (A18), durations may vary from some hours to weeks or even months (Barraket et al., 2013; Points of Light Foundation, 2005). Thus, at least for some disaster situations, working duration is a relevant attribute to a SUVs willingness to help.

A20: Operating Site. Operating sites define locations where SUVs might be needed. Some disasters (e.g. flooding) may have many operating sites, while others get along with one location (e.g. terrorist attack). An operating site is characterized at least by its location, the amount of current and needed SUVs, and the required supporting tasks (Detjen et al., 2015; Hofmann et al., 2014; Luqmann and Griss, 2011).

A21: Kind of Information. Information about operating sites influence the SUV's decisions: operating sites with high demand for volunteers are preferred over those with no need for volunteers (Lange and Gusy, 2015; Kaufhold and Reuter, 2015; St. Denis et al., 2014; BBK, 2014). The kind of information that volunteers receive on different channels and/or media also might influences their decision and, thus, should be seen as relevant attribute for SUVs behaviour.

A22: Location. The location where SUVs live or where they are when deciding to help plays a critical role in selecting operating sites. Usually SUVs tend to help on operating sites that are near to their location (Auferbauer et al., 2016; McDonald et al., 2015; Luqman and Griss, 2011).

A23: Operating Site Preference. As mentioned before, SUVs select their operating site first within their social network and then in a close area to their own location according to the information about need for support (Auferbauer et al., 2016; McDonald et al., 2015; Luqman and Griss, 2011). SUVs, thus, have individual operating site preference (CNCS, 2011).

A24: Travelling. Recent disasters have shown that SUVs usually are pedestrians, however, when individual cars are used for getting to an operating site, additional challenges like blocking emergency routes near the operating sites were reported (Kircher, 2014; Fernandez, 2007). Thus, the kind of getting to the operating site is seen as further relevant attribute for SUV, since it might be influence disaster coordination.

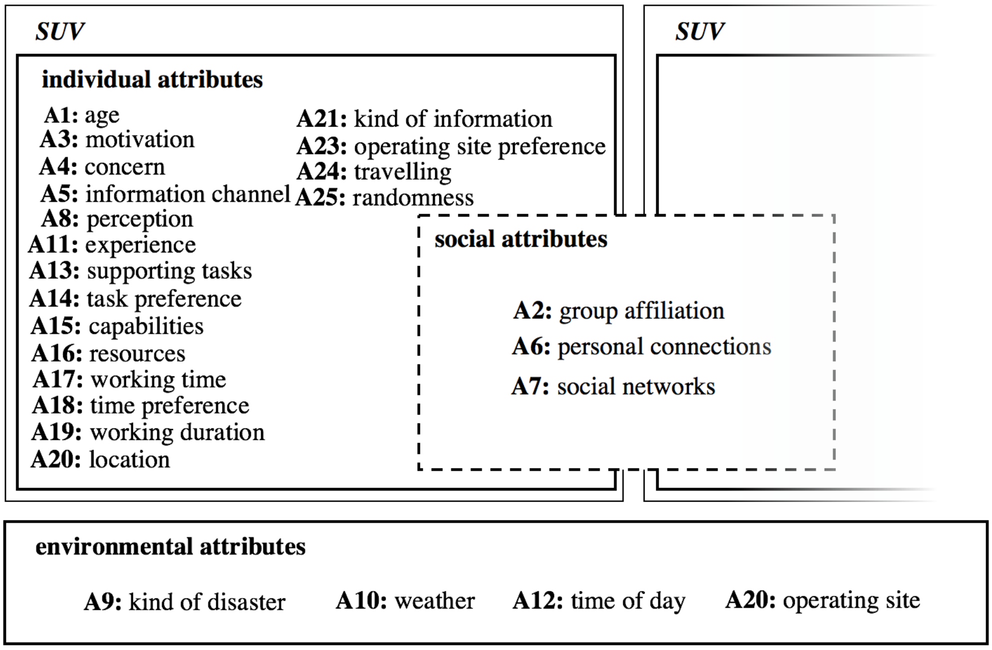
A25: Randomness. Motivation combines only a part of the factors influencing actual behaviour of the SUVs and it is impossible to collect and depict all factors influencing motivation, time preferences, or working durations (Geißler, 2014). Since a SUV may have concrete time preference and high motivation to help, there is still a probability that something unexpected happens preventing him or her from actual helping. Thus, for simulating such fuzziness, a further attribute called randomness is seen as relevant for simulating realistic SUVs behaviour by software agents.

ATTRIBUTE CATEGORIZATION AND INTERRELATIONS

Altogether, 25 attributes were identified featuring or influencing the behavior of SUVs. Although the identified attributes are focusing on different aspects, there exist obvious interrelations. A major insight is that motivation seems to be the key to actual supporting activities and that other attributes affect and trigger motivation directly or indirectly. A further insight is that due to complexity reasons the interrelations are subject of further research. However, some connections can already be identified by the underlying literature body.

Beside the missing concepts for operationalizing the attributes and their interrelations, the identified attributes can be grouped into individual, social, and environmental attributes. This is a contribution to modeling SUVs as software agents and simulating their behavior with multi-agent systems in the future, since some attributes affect the individual behavior of a software agent (e.g. decision to help) while others affect their cooperation results (e.g. group affiliation). Some attributes can be influenced by the software agent itself (e.g. location), others can be influenced by others (e.g. kind of information by disaster management), others are fix in the short run (e.g. age), and others are externally given (e.g. weather). Classifying the attributes into individual, social, and environmental attributes is a basic step for developing software agents. In general, software agents act in a perceive-reason-act cycle (Lind, 2010) which is determined by how software agents perceive their environment (environmental attributes), derive their actions by an internal processing of the perceptions (individual attributes) and interact with other agents (social attributes). The identified attributes, thus, were grouped in according categories (see Figure 1): individual attributes are those that feature SUVs behavior directly, social attributes are those that are related to interconnections between the agent and other software agents, and environmental attributes are those that are externally given and identical for all software agents, however they are perceived by software agents influencing their individual attributes.

Figure 1. Grouped Attributes of SUVs.



According to our literature review, the presented attributes and their classification is the first step fitting relevant SUV attributes to the perceive-reason-act cycle that is essential for the representation of SUVs behavior in an agent-based perspective.

Conclusion and Future Research

A comprehensive literature review revealed that increasing research on using the enormous potential of spontaneous unaffiliated volunteers (SUV) for disaster response exists. However, it also revealed that research on coordination and cooperation behavior of on-site physical volunteers is just in its beginning. While several approaches have been developed and discussed, a systematic and comprehensive testing and evaluation is difficult: real disasters are usually not at hand and field tests or drills are expensive, elaborate, or partly impossible. To close this gap, simulations are promising and multi-agent simulations provide an established method to simulate human behavior. Developing software agents successfully, simulating the behavior of SUVs requires an extensive analysis of their real world behavior. Thus, the aim of this contribution was to identify and to analyze relevant attributes from the state-of-the-art characterizing SUV's behavior. Altogether, a set of 25 attributes featuring SUVs or influencing their coordination behavior were identified and classified according to individual, social, and environmental attributes. This provides a first sound basis for designing realistic software agents, their perceive-reason-act cycle, and multi-agent simulation environments in future work. This is seen as a first necessary step to improve the evaluation and validation of novel research methods and tools aiming at effective and efficient coordination of SUVs in disaster response.

The analysis also revealed several limitations and research desiderata: while identifying the attributes, it turned out that the effect of some attributes is not yet clear (e.g., weather, age) and, thus, need further investigation. In order to obtain high quality simulation results parameterizing the identified attributes and their interrelations is also required and, thus, part of further research. These limitations most likely lead to nonrealistic simulation results when starting with simulations according to the current state-of-the-art. However, since quality of results can be expected to improve by taking new insights (attributes, interrelations, effects) into consideration, the development of software agents based on the identified attributes is a consequent next step of our research. This is realized within a comprehensive research project named KUBAS aiming (a) at an IT-based solution for coordinating SUVs and (b) at a general evaluation method to measure the effectiveness and efficiency of approaches, methods, tools and drills aiming at the integration and coordination of (thousands of) SUVs during disaster response. The methodology of the whole research project follows the "Design Science Research Process" proposed by (Peffers et al., 2006). Accordingly, the paper at hand is part of the second phase "objectives of a solution" and with its results it provides an important fundament for the next phase "design and development" focusing on the modelling and technical implementation of SUV software agents.

Last but not least, the identified set of attributes are expected to be helpful for other researchers and application scenarios, e.g., it might support official forces in coordinating SUVs in general by knowing which factors influence the behavior of SUV. Furthermore, the attributes and their classification might facilitate the development of new coordination methods regardless of the use of IT.

ACKNOWLEDGEMENT

This research has been funded by the Federal Ministry of Education and Research of Germany in the framework of KUBAS (project number 13N13939).

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Agile Emergency Responses Using Collaborative Planning HTN

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ABSTRACT

Emergency response planning is a complex task due to multiple organizations involved, different planning considerations, etc. Using artificial intelligence collaborative planning helps in the automatic planning for complex situations. Analyzing all impacting factors along with plans that are executable can facilitate the decision making in Emergency Operations Centers for an agile emergency response. A main component of a planner is a knowledge base. Although many systems are developed to support decision making in emergency response or recovery, they either focus on specific or small organizations, or rely on simulations. To the best of our knowledge, there is a gap that there is no common knowledge base for provincial level mass emergencies for automatic planners. The multiplicity of the emergency response documents and their structure makes the knowledge acquisition complex. In this paper, we explain the process of extracting knowledge based on hierarchical task networks and how it speeds up the reactivity to a disaster.

Keywords

Collaborative emergency response planning, emergency operations center, emergency response knowledge base, decision support systems, hierarchical task network.

INTRODUCTION

Managing emergencies often require the cooperation of many agencies. Emergency Operations Center (EOC) provide a collaborative environment to facilitate information sharing, resource management, and plan development to respond to an emergency. The main objectives of each organization are defined in EOC by a person associated with that agency, and then is communicated to EOC personnel. The decision makers in EOC work on these objectives, as well as the ones developed by EOC personnel, coordinate all communications, and collaborate on making decisions.

Multiple factors such as information sharing and communication between different organizations (Ley et al., 2014) and managing emergency logistics (Choi et al., 2016) make the decision making and managing of an emergency a complex task. In provincial level or mass disasters, where number of involved organizations and information resources increases, emergency response planning becomes even more complex. Many information systems are developed to facilitate the communication or collaboration between multiple organizations (details can be found in related work section). However, the problem of resource allocation and making sure that a plan is executable regarding the current situation, timing, and available resources cannot be solved with information sharing systems. As a result, these factors should be integrated in order to provide an effective information system that supports planning emergencies.

Different approaches are developed to facilitate the planning. Banuls et al. developed a method for modeling the scenarios, assessing impacts, and planning collaboratively for emergency management (Banuls et al., 2013). In (Diirr et al., 2015), an approach is presented that uses states and unforeseen situations, mapping between these two, and defining the states' dependencies to monitor, suggest, and adapt a plan. Hofmann et al. (Hofmann et al., 2015) present the use of precedence diagram to manage and schedule the activities based on the resources and execution times. However, there is no support tool for the above mentioned methods.

Consider a flood event in which multiple buildings from various zones should be evacuated. The number of people to evacuate, their age, available responders and vehicles, their distance to the buildings, and the transportation route are some of the factors that should be considered in the planning. The actions to be taken and the required resources depend on many factors such as whether the evacuees are seniors, school aged children, or patients of a hospital.

According to Flachberger and Eduard, the information centric paradigm is needed for crisis management (Flachberger and Eduard, 2016). Focusing on the provided information, automatic planning techniques can address the above-mentioned issues while automating complex tasks such as task tracking, impact assessments of each action, and resource management. They can provide different sequences of actions (plans) that satisfy a goal with given constraints such as task prerequisites and available resources. By considering all the impacting information and factors, and making sure that a plan can be executed, automatic planners facilitate agile emergency response management.

Among various planning techniques, we focus on an artificial intelligence (AI) planning technique called Hierarchical Task Network (HTN) and developing a knowledge base for HTN in provincial level emergency management. HTN is used due to its specific features to solve a problem by abstracting the tasks in a hierarchy and then defining an executable plan. The hierarchy of tasks in HTN is similar to the cognitive concept of problem solving by humans and in EOCs. Figure 1 demonstrates a schematic view of an HTN planner. By receiving information from the user about the event and the current situation such as available responders on site, blocked or clear routes, requests of emergency logistics, and etc. it generates a plan – sequence of actions – that is executable with respect to the given and predefined conditions. Other than the planning algorithm, the main component of an automatic planning engines is a knowledge base that is used to analyze different tasks and the conditions that must be satisfied in order to have an executable plan. This knowledge base should be defined for each specific domain based on various actions, conditions, and causalities between the tasks.

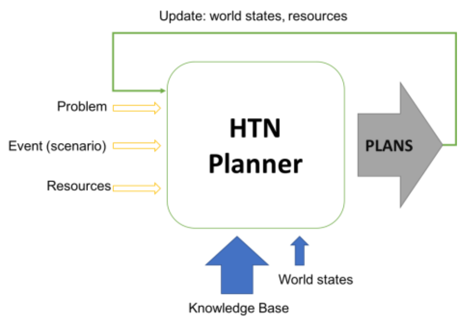

Figure 1. HTN Planner

One of the main challenges of developing such a knowledge base is the multiplicity of the documents and their high-level explanation of the actions for emergency responses. These are the documents that are open to public, and can be found on the government websites. On the other hand, although some actions are specific to each type of event (for example flood, earthquake, etc.), there are a lot of response actions that are shared among these documents; but there are specific emergency response actions developed for each type of event. The emergency response plan documents are long booklets with different sections developed for specific organizations or specific tasks such as logistics, and is intended to be used within its own authority/province.

We believe that developing a knowledge base, independent of a location or organization, can benefit the emergency management in developing countries as well, where information systems are not used widely for emergency management. Such a knowledge base used in an HTN planner, suggest specific set of actions that might be taken at certain times, regarding the event and the states of the situation provided for the planner.

In this paper, we explain the process we used to develop a knowledge base that includes the networks of actions, their dependencies, tasks' hierarchies, and pre- and post- conditions of each task from emergency response documents.

We will review multiple approaches and systems that support emergency management or emergency decision making in next section. Although there are libraries in some works that is referred to as a reference/guidance in specific situations (such as information on specific chemical in a chemical leak event), the others provide restricted information on the use of an actual knowledge base or provide small examples on specific domains which contain only a few actions or tasks, as an experimental study. To the best of our knowledge, a provincial level emergency management knowledge base for HTN is lacking in this field. We address this problem by giving examples of the process that we are using to extract such a knowledge base.

RELATED WORK

In this section, we provide background review in three main classes: Collaborative Planning (CP), Decision Support Systems (DSS), and Hierarchical Task Networks (HTN).

CP and DSS are reviewed to make sure that we include information systems that might use a knowledge base for emergency management. CP in general is used to facilitate collaboration. EOC personnel collaboratively plan for an emergency. We studied the set of works that facilitate collaborative planning or include features that should be included in the system designs for CP in emergency management. DSS is used to support decision making and commercialized version of DSS are available for emergency management. We review DSS to categorized the works that work on emergency knowledge management and to identify systems that suggest plans as part of decision making. In the third sub-section, we present HTN systems and HTNs that are developed for emergency management. Most approaches mainly focus on the software system or architecture of the system to access various knowledge. Other than (Alvear et al., 2013) working on the road tunnels, the reviewed DSS or HTN systems use small applications with a few tasks or only provide information to facilitate decision making. The actual knowledge repository used in these systems are not provided or are specific to small and specific domains. Even in works that develop HTN based planners for emergency management, the focus is on adding properties to the knowledge representation or HTN to adapt emergency management requirements.

Collaborative Planning

Collaborative planning is a process that is used in EOCs, in which multiple agencies collaborate to define a plan for emergency response. The collaboration and interaction methods between people in the emergency management are studied in different works and multiple systems are developed for this collaboration. Fischer et al. (Fischer et al., 2015) study the ways people collaborate to manage an uncertainty situation while working around a table. They propose an augmented bird table and the principles for system designs in disaster management. Qin et al. developed a collaborative system using tabletops for emergency management. They analyze how people can manipulate objects, analyze situations, and collaborate to deal with an emergency while using their system (Qin et al., 2012). In (Doeweling et al., 2013) authors provide a tool that support situation analysis and planning for crisis management with interactive tabletops. They mainly focus on the role specific interactions while sharing the information.

Pedro et al. studied the collaborative features required for the development of software products for fire fighters and implemented and evaluated two applications based on their study (Pedro et al., 2016). Collaborative features of decision making in emergency management are also studied in Wu et al. work (Wu, et al. 2013). They research on system designs to support team work and developed a role based prototype for analyzing and visualizing geo-spatial maps and sharing information. Ley et al. also studied and developed a system porotype for sharing information and expertise between various organization involved in an emergency (Ley et al. 2014). Shatte et al. present a web based tool for collaborative document writing in emergencies (Shatte et al. 2016).

Decision Support Systems

The primary component of the decision support systems is developing a knowledge base or knowledge repository. Zhang et al. suggest a knowledge management framework for the assistance in decision making process in disaster relief (Zhang et. al., 2002). This framework is for the integration of distributed knowledge and information from different resources. The main part of the framework is a knowledge base which acts as a repository and should provide action recommendations for decision makers. Another theoretical approach is developed in (Arain, 2015) for the post-disaster response and a DSS shell. The main components are the knowledge base and the DSS to support the actions.

Collaborative knowledge as a service (CKaaS) for disaster management is used in (Grolinger et al., 2015). The authors explain a case study where the cloud consumer and cloud broker use two KaaS providers to make a right decision about turning off the gas. The KaaS providers include the information about critical infrastructure and best practices and recommendations based on related disaster management decisions. They mention how the simulation knowledge is integrated and used in this case to provide the information. The CKaaS architecture proposed in this paper explains how different KaaS entities containing various information can be integrated together to be used for decision making.

Mendis et al. developed a framework to model the commonsense knowledge in a three phases process (Mendis et al., 2007). The application of their work in disaster management is provided by mentioning the spatial data that is used in disaster management.

Multiple decision support systems (DSS) are developed for disaster management. In (Rolland et al., 2010), authors use resource-constrained project scheduling models (MRCPSP) and adapt it along with an algorithm for disaster management. They provide mappings from the MRCPSP criteria to disaster response scheduling problems such as mapping of late and setup costs to loss of life and personnel moving.

Cioca and Lucian-Ionel studied the DSS and its application in disaster management, specifying a case study on a fast flood warning system (Cioca and Lucian-Ionel, 2010). In (Gadomski et al., 2001) IDA approach is used to make an intelligent DSS for emergency managers. The prototype uses an oil port as the test case. In (Alvear et al., 2013), a DSS for road tunnels emergency management is developed. This DSS uses the decision, incidents, and evacuation models for road tunnels.

In (INDIGO, 2010) multiple information systems for disaster management are represented. They mostly focus on large scale systems or projects funded by governments. For example, RIB (2012) is an Integrated DSS that provides information access for multiple organizations, alerting and sending information, and supporting decision making by providing related information from the libraries, e.g. chemical types and properties in a chemical leak event.

HAC-ER is a prototype disaster management system (Ramchurn et al., 2015). This system provides situation awareness from crowdsourcing and is able to allocate tasks to first responders on the ground and Unmanned Aerial Vehicles (UAVs) and showing the paths. A planner agent that uses Multi-Agent Markov Decision Process (MMDP) to solve the planning process is part of the system.

Hierarchical Task Network

Hierarchical task network (HTN) is an artificial intelligence technique to solve a problem which is close to how human solves a problem or plan. These techniques consist of a set of higher level (more abstract) and lower level actions, such that each high-level task can consist of a set of a more abstract task. A plan is a solution of these tasks when the conditions are satisfied for each action. Each action changes the states of the world and its conditions also can be considered as a set of states that must be true in order that to be an executable task. A plan is changing the world states step by step until it reaches a final state which is the goal or the final solution. An example of an HTN task network is provided in next sections. HTN approaches require a knowledge representation for the domain and a planning process (Castillo et al., 2014).

HTN planners are used in various applications such as web service decomposition (Georgievski and Marco, 2015), robotics (Lallement et al., 2014), and crisis action plans (Castillo et al., 2005). Domain configurable planners can speed up planning by many orders of magnitude (Nau, 2012). HTN planner can solve problems by reducing the search space and is suitable for emergency management. HTN is similar to the process of developing action plans for an incident and provides an effective approach to generate action plans for emergency management. In (Tang et al., 2012) specific characteristics of HTN are named that make it a good candidate for emergency management domain: expressing the real-world problems which is provided by the form of knowledge used in HTN, the hierarchical nature of the task network which represent the goals/sub-goals and provide details for decision makers, similarity of the HTN and the decision making process in emergency management, and its ability to scale up for complex problems where there are thousands/ hundreds of thousands of objects and actions. The final characteristic of HTN is related to its procedural domain knowledge (Tang et al., 2012).

Specific forms of HTN are developed for emergency management. TPHTN is a temporal HTN developed for emergency management (Li et al., 2016). Specific networks named Simple Temporal Network with Preferences (STNP) is used to represent the information of temporal preferences. The temporal expression is also used in the operators and methods of TPHTN. The results of this work are compared against the HTN regarding planning quality and time. The problem designed for this comparison is a small set of operations on the logistics domain and considers only timings. Other than this experiment, there is no information about the use of any knowledge base for emergency management. This is part of a primary work where the authors developed a heuristic search in temporal HTN planning for developing incident action plans (Tang et al., 2012). Similarly, other than its domain, there is no information about the knowledge base used for developing the problem that is used in the planner.

SIADEX is another HTN based planner developed for forest fire fighting. It uses an ontology based knowledge base for the planner and stores the information about the objects, worlds, tasks, and temporal constraints as various ontologies. It has a separate module to translate these ontologies to the SHOP task formation (an HTN-based popular planner) and PDDL (Planning Domain Definition Language) (Asunción et al., 2004; Asunción et al., 2005). To the best of our knowledge, this is one of the works that specifies the knowledge it used and its knowledge base architecture in detail. There is no information on whether the knowledge base used in SIADEX is publicly available and how complete it is. However, the domain is specified for the forest fire fighting.

State based partial order causal link and state abstraction combined with HTN planning are represented in (Bernd and Biundo, 2002) and (Biundo and Bernd, 2014) respectively. In each work, a combination of HTN planning is used and its application on the crisis management is represented.

DEVELOPING EMERGENCY RESPONSE KNOWLEDGE BASE

There are multiple documents on government websites that include information about emergency response and plans for different provinces (Emergency Response Plans, www.emergencymanagementontario.ca). These documents, are high level documents including various information such as: stating different emergency response plan activations, response actions, roles of various authorities and organizations in responding to an emergency, communication channels and information flow, powers of ministers in activation of some tasks or ordering tasks to response, reduce or prevent damage or lose in mass emergencies, different considerations for various actions, situational understanding, logistics, coordination of human resources, facilities, and equipment, access controls and transportation, agencies' communications, and assistance requests.

Extracting a knowledge base that can be used in a software tool is not possible by only using this information as it is. To make the knowledge base, we use the following process, which is shown in Figure 2: Acquiring various documents that contain information on emergency response planning; Extracting information from these documents and making task networks on higher level tasks; Adding the conditions and effects of each action in the task networks and using the considerations for each action; Connecting various task networks and making the highest level task network; And modifying or completing the task networks based on higher level connections, pre-conditions and effects, and other response documents. This is an iterative process to make the knowledge base and update it from time to time. In the following sections, the process in each step is explained in detail.

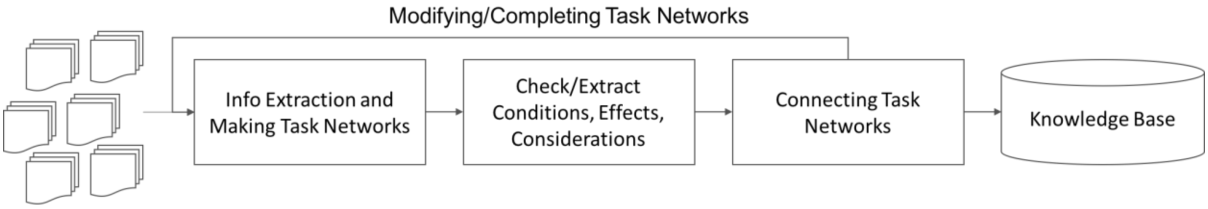

Figure 2. Developing Emergency Response Knowledge Base

Extracting Information

Other than relying on the online and publicly available resources, we have requested emergency response plan documents for different levels of operations (provincial, township, or organization) from experts in this area and from our industry partner C4i Consultants Inc. (http://c4ic.com). These documents are in various response domains, including earthquake, flood, oil and gas, and etc. The goal however, is developing a usable knowledge base for all levels, which is not location specific and can be used in different locations.

Making the Networks

Based on the information in an emergency response plan document, we can identify the main high level actions and responsibilities for different organizations in responding to an emergency. When constructing the networks, the primitive tasks can be found under the required response actions for each organization or authority, the required resources, the various response actions in different conditions, in an explanation of an action, or list of possible responses. There are two approaches to translate each sentence or response action to a task:

- Breaking a sentence or response action down into two or more tasks
- Combining sentences or response actions to a higher-level task

Examples of the former is *DIRECT AND PRIORITIZE RESOURCES* sentence, which includes two separate actions of *RESOURCE PRIORITIZATION* and *RESOURCE DIRECTION*. Also, the actions can be combined together to make a higher-level task in the network. For example, *HIRING DRIVERS* and *HIRING EMERGENCY RESPONDERS* actions should be determined under a higher-level task, *HIRING HUMAN*

RESOURCES, in the network. An important aspect of this creation involves the data management of these tasks; Thus the network is created using the principles of a Metamodel where the data gets classified into efficient structures (Bénaben et al. 2016).

Checking Conditions/Effects

When making a planner, each executable task requires some conditions to be satisfied. Without these conditions – considered as the prerequisites of the action – the action cannot be complete, and therefore, the plan including that action cannot be executed. There are various considerations in the provincial level emergency response plan documents that also should be taken care of for each action. Examples of the conditions and the considerations are explained in the following:

To evacuate a building, we should have enough personnel, either emergency responders or volunteers to help in the evacuation process. Moreover, sheltering areas should be available with vacancies for the number of people evacuated. The transportation available, the distances' considerations, and many other factors should also be considered. Furthermore, the evacuation order should be issued first, and must be done by the person in power. These orders and some of the conditions are only stated as considerations or in the powers and responsibilities of ministers, etc. Therefore, when defining the tasks and pre-conditions for each one, all of these considerations should be included, in addition to rational and explicitly stated pre-conditions such as available personnel.

When an action is performed, it has some effects on its environment. Having a list of what are the effects of each action that affect other tasks in the planning process is an important part of developing a knowledge base. One example of such an effect can be impact assessments. When the damage is assessed for an impact area, the effect of this action is having the list of damaged building, routes, etc. available. As a result, it can be used for other tasks later on, since the states of our world are changed.

Connecting Networks

When making the task networks, we build a network for highly relevant tasks at once. For example, including all the actions for procurement coordination. As a result, at the end there are several task networks, but they are separate islands that should be bridged together. These networks are connected together by defining higher level tasks that can be linked to the highest task in each network. In Figure 3 three task networks are represented for controlling access to/in the impacted area, increase human resources to support emergency response, and providing essential supplies.

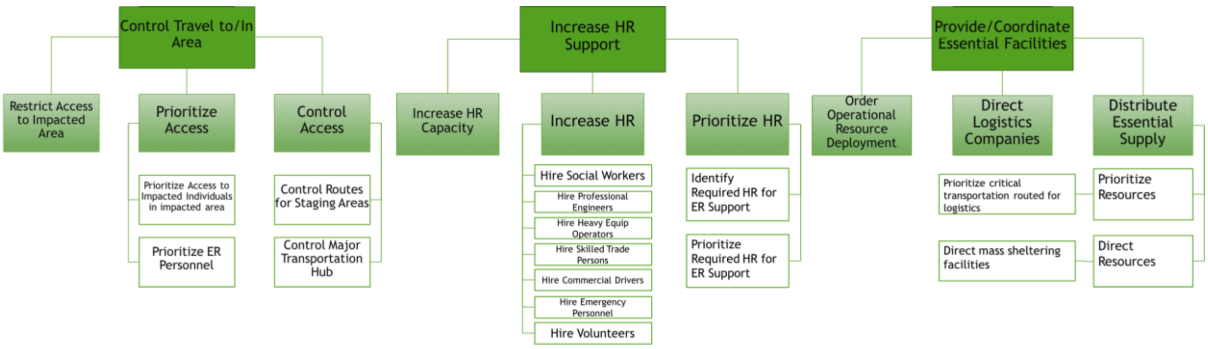

Figure 3. Three task networks

Modifying/Completing Networks

To complete a network, we should consider the following points, which affect completion or modification of a task network:

- Pre-conditions of each action (primitive task)
- Effects of each action (primitive task)
- Connection of two or more networks
- Effects of each action (primitive task) on the tasks of other networks

In the previous step, multiple networks are connected together to make the whole task network for the planner. In this process, and also in the step that we determine pre-conditions and effects of each action, some missing actions are identified. For example, one condition for evacuation is availability of personnel. However, identifying the available personnel and their expertise is not defined previously. Therefore, we also require a task network for acquiring information about the personnel, their information and expertise, locations, numbers, updating all this information, and etc. The same applies when connecting multiple networks together. One such example is increasing the support for human resources and available personnel. We should also take care that this task will affect in other networks such as logistics, sheltering, transportation, essential supplies, and etc. Again, for each of the task networks that are connected together, we might notice that some actions should be added to each network based on the ones it is connected to, or it can have an effect on.

Completing and modifying networks is an iterative process and requires a lot of attention. Each time a task is updated, new connections are made between the networks, or new information is received, an update can be applied to the whole or a portion of each task network.

One example of completing a task network is shown in Figure 4. This is a modification that is required when considering the actions of two networks

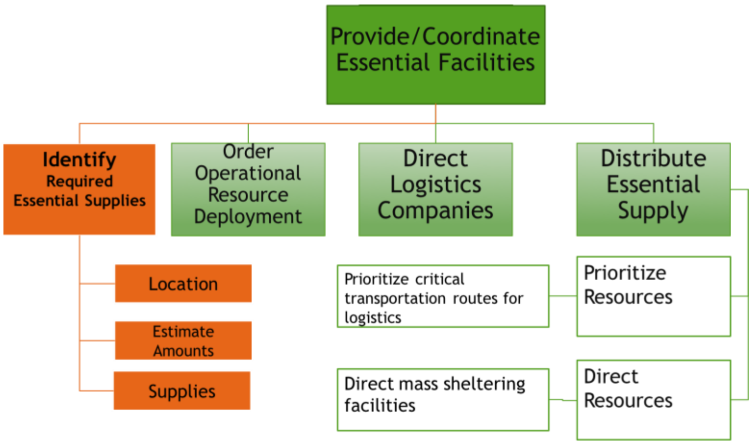

Figure 4. Completing/Modifying a task network

DISCUSSION AND IN PROGRESS WORK

Interview

We have set up interviews with people in this field. We interviewed two persons, one directly working in an EOC and involving in setting the objectives and make them available to the EOC manager, coordinating, and etc. These interviews are done concurrently to the process of knowledge extraction to make sure about some features of the planner we are working on are useful and gain more insights about the process of emergency management in EOCs. Other than interviews, we discussed the process of HTN knowledge base with an industry partner, C4i Consultants Inc. (http://c4ic.com/), which is a software development and training service company for emergency responders. Based on our discussions, such a knowledge base and planner can benefit the emergency management EOCs. There were also concerns about the information that should be included in the system and specific processes. Obviously, no evaluation or direct feedback is received since the system is not developed yet.

Work In Progress

The development of the automatic planner in this work is a part of a bigger project for the development of Emergency Operations Center of Future (EOCF). EOCF is intended to bring new technologies to EOCs in order to make emergency response more efficient (Chan et al. 2016; Marbouti and Maurer, 2016).

Currently, we have extracted a big portion of the higher level knowledge base from provincial level emergency response documents. Part of this knowledge is translated to a format that is useable for an HTN planner. We intend to require higher level documents to complete the network, and also include detailed knowledge to complete the task networks in lower levels of actions. Working on the planner and making the list of states that should be included as a world state is in progress.

Metamodel Implementation

After having iterated through the previous steps, a concrete, implementable Knowledge Base is able to be produced. The implementation of this Knowledge Base can be taken from a specific form, to a more general context by creating a Domain to represent the Knowledge Base. This Domain is then able to be parsed through the HTN planner to produce a world state.

As shown by Benaben et al., Domains can be represented by the operators of the Knowledge Base (Benaben et al. 2016). As previously mentioned, we have developed a working, sample study to demonstrate the applicability of the HTN Planner. The sample was designed to mimic the evacuation of a hospital, but at the most High-level abstraction available, as shown in Figure 5. In this case only a few operators are needed, which allows for ease of not only study, but also replication.

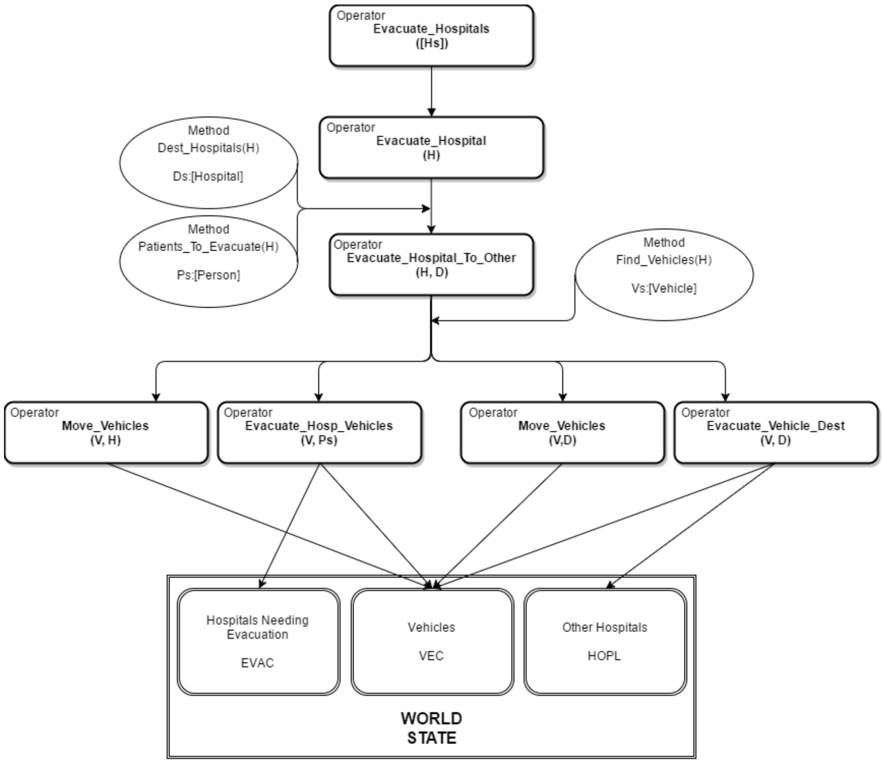

Figure 5. An example of a created Knowledge Base

In this example, the operators are shown in a concrete hierarchy, with their relationships extending downward until the world state is affected. A Knowledge Base can be defined where;

WorldState = [Entities]
Entities = (name, [attributes])
Operator = (WorldState, [methods], [Operator])

Comparing this to diagram 5, we demonstrate that an abstract Metamodel can be used to build a non-primitive syntax for a Knowledge Base.

Note that additional methods are required to be performed within operators, and that these methods do not require to be classified as operators themselves. With this representation the world state is able to be affected by an outside influence, allowing for the ability to re-evaluate the hierarchy during run-time, as the operators use the world state within the external methods to determine the proper assignments of sub-tasks. This is an implementation the idea of agility noted in Barthe-Delanoë et al. which allows for a dynamic world (Barthe-Delanoë et al., 2012).

Discussions

Additionally it is also worth mentioning that knowledge acquisition is not a new field. Multiple algorithms based on natural language process and text mining exist to extract knowledge from different resources. While this is a valuable approach, many of the knowledge extraction systems for emergency management are developed ontologies, knowledge models, or information extractions from social media. One example of a knowledge acquisition in emergency management is an ontology developed for mass emergency medical services to be used an intelligent DSS (Haghighi et al., 2013). Many works rely on crowdsourcing and knowledge extraction from social media (García-Santa et al. 2015; Xu et al., 2016). In emergency response planning, we need to rely on a concrete and reliable knowledge base. The tasks networks that we are developing can be used as a base knowledge to build upon or update with automatic knowledge extraction later. We are developing prototype knowledge base and in order to be used in real world, these networks should be validated by experts in emergency management.

ACKNOWLEDGEMENT

This project is being developed by the coordination and support of our industry partner, C4i Consultants Inc.

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Simulations and Serious Games for Firefighter Training: Users' Perspective

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ABSTRACT

Simulation and serious games (SSG) are advocated as promising technologies supporting training in emergency management (EM). Based on an investigation of SSG use for fire fighter training in nine countries, this paper is examining key elements and success factors that can counteract potential obstacles and challenges of SSG implementation. Data comes from interviews and observations with users and responsible managers from user organizations. By contrasting the different incentives and views regarding the SSG use, this paper contributes to a better understanding of SSG integration into organizational practices. Only by connecting the local, organizational strategies and user requirements with technical values and concrete examples can the SSG usage be experienced as successful. This connection requirement is by far not obvious since values are formulated differently by the main stakeholders and the benefits at one organization are not necessarily the same as at another. In this context, the added values of SSG solutions need to be more explicitly connected to the goals of traditional classroom and live training.

Keywords

Emergency management, firefighter, user, training, simulation, serious games.

INTRODUCTION

The use of simulations and serious games (SSG) is increasing in emergency management (EM) training and education. SSGs are technologies providing features that can support high user experiences and learning, are using game technologies and game elements for applications aimed to support work, not only /entertainment. They are often built on existing game technologies on which reality-like, digital scenarios can be constructed. They can include various game elements such as tasks to accomplish, role-playing, levels to achieve, or goals to reach. Promises from SSGs to support everyday training activities are many, from keeping pace with rapid technical updates, to more intuitive, easier, and engaging applications to increase motivation to train, see e.g. the Introspect Model (Lamb et al., 2015). SSGs provide better insight into new situations, allow accessible training with greater safety and less harmful impact on the environment (e.g. Crookall, 2015; Williams-Bell et al., 2015), and better support for decision making (Chittaro et al., 2015; Molka-Danielsen et al., 2015). During the last decade, the cost of SSG applications and technologies has decreased and the technology has become more accessible (Ott and Freina, 2015). These benefits and promises often overshadow possible problems related to how implementation can be accomplished and how successful use can be achieved (Connolly et al., 2012).

This paper aims to provide a better insight into the SSG technology usage for firefighter training, which in this paper includes incident commander training. It examines key elements recognized by user organizations that can counteract potential obstacles and challenges of SSG implementation. The data comes from interviews with user organizations and observing actual training situations within EM training. EM training often involve an incident scenario in which the trainees have to understand the situation, make the right decisions, act in their own teams and collaborate with other teams. While the focus in this paper is on firefighter training, parts of the data come from the ambulance and the police education and training. By contrasting the different incentives and views regarding the SSG use, this paper contributes to a better understanding of the benefits and possibilities of these technologies. This knowledge is needed, since the different actors need more proper methodologies to handle study results (Connolly et al., 2012) and more illustrative examples on SSG integration in training to understand how they need to be applied to their own educational goals (Backlund and Hendrix, 2013).

Additionally, there are examples of organizations that invested in the rather costly SSG technology several years ago, in which the utilization of the technology is very limited. For example, utilization may be restricted to showing informative pictures or films exemplifying scenarios or practices from specific places (Heldal et al., 2016). Such examples can be created without expensive resources or licenses for SSG technologies and applications, but they cannot possibly achieve the same benefits simulations can offer (Yaman et al., 2008). Procuring SSGs and not using them indicates recognizing the strategic importance at a top level, but not prioritizing it at the operational level. Technology resistance is not a new phenomenon, and may even be beneficial for an organization, for example if older technologies are replaced by newer ones without enough advantages (see e.g. (Adner and Snow, 2010)). However, having a technology without clear reasons for it and not being used, can be confusing (Toftedahl et al., 2012). To better understand the mismatch between training and SSG values experienced by the procuring managers and instructors responsible for training within the same organization is another purpose of this study.

Another important question when introducing SSGs concerns its role in relation to the examined situation: that is if SSGs can replace or complement the training methods used today? Therefore, we also address the questions whether user organizations experience specific values using the SSGs, and if so, if the values concern classroom training or live training.

The EM referred to in this paper concerns handling accidents and incidents in the first instance, and mainly the incident commanders on scene. In this paper we use the name ‘firefighter’ for the different roles within the Rescue Service. The technologies are - in a broader sense – simulation and serious games, but may also include elements of gamification; hence the SSG abbreviation is used in a broad sense. In the study the main SSGs known to the user organizations are examined: XVR[1], RescueSim[2], Vector Command[3], ADMS[4]. Strangely enough, users consider even the fire and smoke pictures and animations rich Fire Studio[5] as simulation or virtual reality. The reason for discussing different SSGs during the interviews was to obtain a broader understanding of users' opinions towards SSG technologies, in general. For this study user experiences are also referred to as impressiveness.

BACKGROUND

Firefighting is a physically and mentally demanding occupation, besides being potentially dangerous (Williams-Bell et al., 2015). Firefighters have to make many time-critical decisions in possibly life-threatening situations where their task is to protect the safety of civilians, themselves as well as buildings and other valuable objects. Due to emergency situations being unpredictable, time-critical and high-risk situations, firefighters have to go through extensive training in order to increase and maintain their preparedness. The background of this paper is based on information about firefighter training, the role of using SSGs for training, how SSGs can be treated in new unforeseen situations and why some procured technologies are not used.

Firefighter training

The most common form of EM training is in classroom-like situations and via live training (Hammar Wijkmark et al., 2015). Both training forms are necessary; in classrooms you learn the theoretical parts, regulations, chemistry etc. and in live training you learn how to handle equipment, experience the heat, time pressure etc. to gain important knowledge and acquire necessary skills. Usually, there are already proven methods to develop, conduct and assess the training for both situations. Live training requires extensive resources of training personnel, specialized facilities, equipment and well-planned scenarios. According to earlier researches, SSGs cannot replace either classroom training or live training (Williams-Bell et al., 2015) or evaluations (Girard et al., 2013) at the present stage.

How SSGs complement other training forms?

Technology in general, and SSGs in particular, may add additional values to classroom training and/or to live training, but have several hindrances considering defining these values, which mainly result from differences in the

[1] See further information on the developer and their products: http://www.xvrsim.com/
[2] See further information on the developer and their products: http://vstepsimulation.com/
[3] The company Vector Command (http://www.vectorcommand.com) was integrated in VStep Simulation 2014
[4] See further information on developers and products: http://www.trainingfordisastermanagement.com/
[5] See further information: http://www.digitalcombustion.com/

applied settings (Schaafstal et al., 2001). Existing studies are difficult to compare due to different study designs, methodologies, or differences in applied technical features (Connolly et al., 2012).

Additionally, EM training is also influenced by changes in society. EM also has to deal with new issues and rescue operations are affected, e.g. access to resources in large cities differs from access to resources in rural areas, even if the requirements to effectively manage a situation are the same at both sides, materials in our houses, cars, clothes etc. are changing, objects involved in a situation can be too large, too small or too dangerous. The types of incident nowadays include terrorist attacks and new types of chemicals etc. Even the magnitude of accidents is changing. Harbors cannot be closed to practice large ship fires (Jansen, 2014), and the same fire cannot be repeated multiple times in the same way to allow examination of large numbers of firefighters in the same manner (Lamb et al., 2015). Many of the new changes are not included in training today. SSGs offer the possibility of supporting training for these new and constantly changing situations.

Already recognized training values with SSGs

Training for preparedness of emergency situations is an extremely challenging task and these events cannot be arranged as frequently as desired and run as many times as desired in an equal manner. For these reasons, SSG is often advocated as a complementary method for EM training. The use of SSGs promise values as: allowing more frequent training for many, possibilities to train the unexpected, and allowing better evaluations (Hammar Wijkmark and Heldal, 2015).

Training that includes unexpected events in time-critical and life- threatening situations that allow the firefighter to experience and handle such uncertainty and stress is an important part of the education. How to train for 'the unexpected' is far from being obvious. For example; an instructor can prepare to examine a hundred firefighters in a live simulated scenario like a complicated traffic accident involving vehicles transporting hazardous goods. The scenario can involve fire, smoke, role-players and leaking gas. It is difficult to reproduce the exact same conditions and to conduct the training in the same manner for all firefighters (Chittaro, 2016; Williams-Bell et al., 2015). It is almost impossible to include instant realistic reactions to wrong decisions or actions such as for example the wrong extinguishing method. For examination of incident commanders, it is important to be able to follow the same situation and allow commanders to experience their role, several times, as similar to a real situation as possible. They are examined on their problem solving skills, which entails rerunning the same situation and discussing how they are thinking is the most important. This would be difficult without computer-based simulations (Mumma, 2016).

Possible reasons for non-using SSGs

Between the many impressive benefits of SSGs, there are also additional ones, e.g. easier access to information and to expert knowledge anytime and everywhere, by access to naturalistic training situations with safe training conditions (Molka-Danielsen et al., 2015) by distributed and group-based training and learning opportunities (Crookall, 2015) and by traceable actions and repeatable scenarios for debriefing and evaluation of a practiced event (Girard et al., 2013). The latter provides a learning environment where learning from mistakes is possible, in contrast to real-life settings. Being able to use SSG technology for distance training is particularly attractive for many Scandinavian organizations due to the large number of small rescue services in rural locations (Heldal, 2016).

One of the possible reasons for non-use of SSG can be the confusing message from research. Even though studies argue for additional values with SSGs (see e.g. Lamb et al., 2015; Jansen, 2014; Schaafstal et al., 2001) there are other, warning studies for possible negative effects. Examples for negative effects are: difficulties to provide as accurate and dynamic life like scenarios (Williams-Bell et al., 2015), people learn wrongly or miss important situations needed to handle real accidents (Frank, 2014)), how the instructors' engagement and involvement influences learning outcomes (Alklind Taylor, 2014) etc. When some research argues for added values while other research warns for negative effects this can be confusing for potential, new users, especially if they already have established methods and evaluations showing actual, required training outcomes. For us it was beneficially to consider two important phases of technology implementation: the *pre implementation* and the *post implementation* phases (Venkatesh et al., 2008). Non-use after procurement is an indication of problems with pre implementation and this phase is important for many user organizations. There are stories exemplifying procurement, but not use (Heldal and Hammar Wijkmark, 2015). In this this study the potential beneficiaries having access to the technology are referred to as non-users.

METHODOLOGY

In order to better understand reasons behind use and non-use, our approach included exploring situations where SSGs had been successfully implemented and were used in training programs. To obtain a picture of the use of SSGs for EM training in Sweden and Europe, interviews and observations were conducted with relevant stakeholders from organizations in nine different countries. The countries were identified via researchers and conferences relevant in the area (as earlier reported by Hammar Wijkmark and Heldal 2015). This contrasts the results from Denmark, Estonia, France, the Netherlands, Norway, Portugal, Sweden, the United Kingdom, and Singapore based on 35 interviews and observations (see Table 1).

The interviews were constructed around at least twelve open-ended questions exploring the respondents' views and experiences regarding SSG's use regarding potential benefits, problems, and risks with using, maintaining or changing SSGs, and the applied conditions describing experienced values of the technology. Each interview lasted between 45 minutes and two hours. The observations were during training and examination of firefighters from Portugal, France, Sweden and Estonia, and lasted approx. 40 minutes for each occasion. As an example, Figure 1 illustrates a training situation, where the learners were trained to handle a situation meanwhile facilitators (see Figure 2) were running or assessing the training from another room in. On the wall stands a motto: 'The right person, making the right decisions at the right time, for the right reasons' (from Lamb et al., 2015).

Figure 1. The learners screen when practices handling an accident in a room.

Figure 2. The roll with learners (left) and facilitators (right) in separate room.

Usually, an assessment, if practiced e.g. in UK or Estonia is divided in the following main parts: information, training, assessment and self-evaluation, and evaluations. The observations in this paper are mainly regarding information and training activities.

EXAMPLES AND OPINIONS ON SSG USE

Benefits

Organizations considering that they implemented SSG successfully also recognized that the success was exclusively dependent on a well-planned process and supporting resources for the introduction of the technology. Motivation was gained by formulating concrete improvement needs, by addressing otherwise '*impossible'* situations and by providing enough resources. An example for handling otherwise impossible situations is from the Port of Rotterdam in the Netherlands. They needed to train large groups in the light of the impossibility of setting up live training at a huge port that could never be shut down (Jansen, 2014). The Estonian Academy of Security Sciences is an example of an organization with enough resources available during the launching period. They recognized the value of SSGs when they planned to build an academic program for emergency management and had support from an EU funding (Mumma, 2016). According to a manager from this organization (expressed at the interview but the citation with data comes from Beerthuis (2016)):

'*Virtual reality enables us to train more people simultaneously, which leads to bigger savings. Although we need to conduct further research on the results, our non-formal assessments demonstrate that students who participated in virtual reality training tend to make approximately 30% less mistakes in routine procedures in real life conditions.'*

The Chechire Fire and Rescue Service in the UK did not have other possibilities to train all firefighters in the area and developed a long-term investment plan for correctly utilizing SSGs:

'*The organization has invested approximately £500 000 in the build of the suite and has further salaried costs for the team that deliver the training…*[and]…*acceptance of simulation as an assessment tool. We are currently at the point of developing our next 4 – 5 years of development in the incident command suite … to provide an immersive real world experience*.'

While the study shows examples and conditions for successful use, it must be recognized that most examples involved local organizations rather than nation-wide public safety agencies. The use consisted of integrating SSG in selected training elements and not into complete certified or formal education curricula (except for Estonia and the UK).

Interviewing users from different countries led to the observation that cost has different meanings for different organizations. The cost of simulation-based training is often compared to live training at some organizations (Estonia, Cheshire in the UK, Port of Rotterdam) while in Sweden, for example, the cost also includes long distance travelling costs from faraway places to one of the two training locations in Sweden. Accordingly, being cost effective means something else for Cheshire Fire and Rescue Service, which in 2013 conducted 700 training and assessment occasions using SSG. Exact costs were not available, but it was indicated that comparing with the cost of the same training scenarios live on a training ground, this represents a saving of several million pounds for UK. Cost safety were mentioned as main reason at the Fire Department Gelderland Midden in the Netherlands to train 200 truck leaders, 25 officers and 15 specialists in hazardous substances on various training levels for 1½ years. At the Estonian Academy of Security Sciences management states:

'*In our case it saves a lot of resources- imagine to do a plane crash simulation in real life conditions to train the management skills of that incident. That would cost too much.'*

In France they also see new benefits of using SSG technology to evaluate new equipment and tools within an exercise. For example, the use of a drone in a wild fire cannot be exercised or evaluated in a live wild fire:

'The main reason for developing training using SSG technology is to enable training and exercise in large, long scenarios. At a wild fire for example, the Incident commanders on the ground are trained in communication skills, commanding the water bombing aircrafts. It is important that the incident commander can hear the sound of the aircrafts and this would be too expensive to conduct using real airplanes.'

Even if there are many training situations at the Oxfordshire training center in the UK, resources for training can be problematic, which also influences developers. The same opinion was formulated by a manager:

'Budget is the largest concern for Fire Rescue training today. In a troubled economy, many cities and states reduce budget to Fire Rescue making it difficult to get the right equipment needed for training'.

However, comments on developing new functionalities are required. According to a manager from the Zeeland Safety Region in the Netherlands one of the main benefit of *'virtual reality'* is:

'..that via using it sudden changes can be introduced, for example for increased smoke, or a new type of smoke, characteristic to another material. This may force the trainees to rethink the situation and act differently.'

Cost effectiveness in Scandinavia, however, means something different due to long distances and large rural areas with mainly part time firefighters. While the interviews acknowledged the need for more training and self-lead-training for learners, many instructors also felt that they needed more instructions regarding building up new training and education plans with SSGs. In Sweden the opportunity to train part time firefighters at home or at their fire station and follow sections of the training on a distance learning basis with possibilities to train in '*multiplayer settings*' is named several times as essential.

'*Even if the participants come to campus meetings there is little time to do what needs to be done. More training would be needed*.'

The interviews acknowledged the need for a more coherent technology that not only supports training and learning but also different levels of competence development based on actual situations and not taking into account the instructors' different competence. The role of the instructors is almost the most important for the introduction of technology, since aligning goals for overall objectives differs from aligning goals for '*daily*' use, cf. to (Alklind Taylor, 2014; Ott and Freina, 2015). However, according to the studies and acknowledged thorough during the interviews the instructors may require additional technical support and actual information for important updates.

Current SSG usage limitations

The study reveals a somewhat hesitant attitude towards integrating SSGs into firefighter training, especially for organizations already having recognized training and evaluation methods, e.g. Sweden and Norway. A few instructors (6), with limited or no practical experience expressed their fear of using SSGs. They considered the

SSG technology to be too complicated, costly. Additionally, as one person expressed, it builds up a false sense of security:

[I can imagine there are…] *'...possibly false security experiences based on simulations. Like training chemical spills. There is a risk that the learner does not really appreciate the seriousness when later he is standing there in a real-life situation.*

While there are smaller applications, often available for free or at a low cost that supported specific parts in the training program, their procurement and use are also limited. Their use is often initiated based on personal interest among the instructors. SSG tools, in general, are not used and are not integrated into many trainings.

The interviews also showed that certain groups were not familiar with what SSGs are or what the difference between SSGs and games is. Considering SSGs as games made it certain that users did not take SSGs seriously (Hammar Wijkmark and Heldal, 2015). Managers and instructors from user organizations were not always aware of differences between SSGs or e-learning. As we pointed out earlier, the users were often afraid from the price of the SSGs, or how to trust them. Even after procurement they have difficulties to determine what they can do to make SSGs beneficial.

There are too many different technologies available at the different organizations, and for many end user organizations this can result in confusion. Which scenario needs to be defined, by whom and how are not obvious at the user organizations. Most of the user organizations in this study used XVR or RescueSim for training. While making an interactive simulation based on a realistic description (see Figure 3) takes usually 10-15 minutes for an instructor familiar with the technology, this is very hard for an instructor that is not.

When interviewing participants from emergency management (pre hospital education) from Norway, for example, they expressed worries about handling too many different technologies or versions of technologies. Too many technologies can be experienced as time and resource consuming and can cause internal communication issues between the instructors. They believe that: 1) Instructors needed to help each other out, and therefore they need to have roughly the same skills in managing technologies, 2) SSGs should not be too diverse since different technologies need to be handled differently, and 3) technologies from different vendors should be avoided if possible, since potential problems and errors entail risks that service technicians from several vendors need to be on site and cooperate to solve.

Figure 3. The demonstration of constructing a fire scenario in a student flat in a building took 10-15 minutes.

Instructors are also afraid on priming effects, e.g. trainers learn not expected, wrong issues in the digital environment. This is described by Frank (2014) as *gamer mode.* He pointed out that trainers can play the game only to win and no longer to maintain the same professional attitude as they would in a real training session. Frank defined the gamer mode as a conscious attitude of the player to accept and not question the game rules and objectives. He also emphasizes the importance of debriefing after the game as a learning opportunity.

Table 1 summarizes users from the countries, the data collection methods and indicates overall experiences.

*Table 1. Data was collected via 35 interviews and observations (*are not with ambulance or police education)*

Countries	Data	Overall experiences
Denmark	Interviews*	Non-use for firefighters, according to our present knowledge
Estonia	Interviews and observations	Positive experiences during more than 10 years. During the last few years several scenarios were defined to better suit their own environment with better understanding decision making cycles and explicit educational goals implemented in the SSG used (the XVR system). 400 Incident commanders are trained and assessed using SSG technologies every 2 years.

France	Observations	Positive experiences and a number of technical staff working to develop scenarios for training. They conduct about 700 simulation based training days per year.
Netherlands	Interviews	Positive experiences and widely used. Two major developing companies are situated in the Netherlands. One of the most impressive SSG based training is for the emergency response personnel at the Port of Rotterdam. 'We cannot train otherwise' states the emergency response officer in charge.
Norway	Interviews*	Moderate use with the ambition to use. Here mainly training for the ambulance nurses was investigated.
Portugal	Observations	Positive experiences with ambitions to better exploit the possibilities of SSGs.
Singapore	Interview and observations	Positive. A great new simulator center with different simulators, from haptic based systems to newer scenarios using SSG technology.
Sweden	Interviews and observations	Tentative use, during the last ten years but positive attitude and plans for increased use (Toftedahl et al., 2012). There were great ambitions to use even immersive simulations (Lebram et al., 2009). The firefighters have possibilities to use different SSGs that can be included in their education.
United Kingdom	Interviews	Positive experiences of training large number of incident commanders (Lamb et al., 2015).

PLANNING SSG TRAINING

The ability to continuously develop illustrative scenarios for training while also receiving technical updates needs to be taken in consideration when using SSGs. One of the interviewees from Estonia described the added value of SSGs for the past four years with benefits in both training and assessment, but he also described the risks that instructors can face if they are not updated and do not plan to integrate SSGs in their education. They are not necessarily good enough in their roles, especially in the beginning. To provide training situations with increased user experiences and awareness about real goal requires the instructor to provide good counter play, injects, and present appropriate consequences for decisions and actions. He illustrated a few negative aspects, e.g.

'*One, for example is that if you do not have a good team of instructors the games do not work together. They [the instructors] need to be very competent in their professions and know the learning methods and technologies. The wrong approach sticks in a student's mind very easily. The development of those products is resource-intensive.*'

Many instructors mention that learners do not accept new forms of training since it is not considered to be realistic:

'*Some people may be skeptical about simulation or use it as an excuse if they fail to pass an assessment. Frequently the term "I would have done this in the real world" is heard from candidates by our instructors. However, we are four years into using virtual training and candidates should be used to our organization's training and assessment methods*.'

While the interviews acknowledged the need for more training and self-led/directed training for firefighters, many educators also felt that they needed more instructions regarding training and education with SSG. Obstacles and challenges that were identified during the interviews from the behalf of the educators, seem to originate from one of the following reasons: a skeptical attitude towards the technology, a mismatch of expectations, or insufficient competence affecting the willingness to incorporate the new technology into the teaching practice. The attitude towards SSG was sometimes rather skeptical. It was expressed by the opinion that SSG is not an appropriate technology at all:

'*Games and learning do not usually belong together. Maybe it's a generational issue. From my perspective I may have a hard time to convince some people to use it ...*'. Another respondent expressed the fear that SSG would give a false and possibly dangerous impression:

"[I can imagine there are*] possibly false security experiences based on simulations. Like training chemical spills. There is a risk that the learner does not really appreciate the seriousness when later he is standing there in a real-life situation.*"

There were also concerns regarding instructors' competence and mismatch of expectations. They considered SSG technology to be too complicated and too costly, and not '*enough to begin to use'*. SSG software for training can be considered as an empty framework with a large number of available elements from which own, organization-specific training scenarios can be defined. This feature allows for local customization of training scenarios, in order to create highly meaningful learning situations. However, instructors did not consider scenario development as part of their job, due to the lack of skills and time.

Another concern was raised, which addresses the reliance of offered content and the quality of visualization, as well as the competence of instructors:

'[The scenario is] *lifelike, but also not. It can easily be used in the wrong way. If you do not have knowledge about how it works, there is a risk that they will reject it after testing it a little. Not having a trained instructor is a risk.*'

As mentioned earlier, some of the respondents were not aware of the possibilities of SSG. As we pointed out earlier, these technologies are often treated as e-learning technologies. Since e-learning technologies are used by almost all organizations and the added value of SSGs is not known, there is an unwillingness to change to something that is unclear. This is an opinion described in Sweden, Estonia and Denmark. According to a manager:

'But still, I witness the outdated approach to e-learning as the biggest enemy to simulations and serious gaming development- the shift or change of paradigm should change that the new generation is not in the schools to take in passive information- they are there to get experience- learning should be well aimed and designed, interesting and fun.'

Anchoring SSG scenarios to real life situations: The '*wow*' effect through two observations

Even if SSGs are recognized, sometimes illustrative examples are needed for people to understand its superiority. These examples can come from a better connection to real life or actual problems. In the following two observations we illustrate these effects:

During an observation in Portugal, nine days after the terrorist attack at the Brussels Airport the following observation was made: A psychological assessment team of four psychologists were training in realistic SSGs scenario(s). The assessment team was able to move around by car in the affected area, and talk to rescue personnel and other physicians. Their task was to assess the situation and make decisions and plans based on their actual observations in the scenario. This training was realistic since Portugal has a high risk of earthquakes and tsunamis. However, right after the exercise the instructors changed the scenario to illustrate the possibilities of the technology, and showed a very actual scenario built up right after the bombings at Brussel Airport, but placed at Lisbon Airport, and the people got much more involved. They suddenly realized the power of visualization and the potential of SSGs. The *wow* effect expressed by the audience was astonishing. Via this example they also understood the importance of working with realistic simulations at their own environments. Even the first training scenario became more important. Also their own training certainly became more relevant.

The second observation of a *wow* effect was noticed during a training session in Sweden, involving persons participating in the study. Two technical experts, assisting the training, heard the news about a railway accident involving hazardous goods (sodium cyanide gas), in a city nearby. While waiting for the next training session they designed an SSG scenario based on the real accident and showed it for the participants immediately after they finished their day's training. The technical experts developed two alternative training scenarios, a worst-case scenario with leaking gas and another, best-case scenario, without gas leakage. Seeing the simulated scenarios created in 'such a short time' for the real accident, surprised the audience, since the accident situation was not only real and recent, but still ongoing. They expressed their appreciation for the application and particularly for the handling of two possible cases.

REFLECTIONS AND FUTURE WORK

Experiences from some countries (Estonia, France, the Netherlands, Portugal, Singapore and UK), show that it is possible to experience higher effectiveness for firefighter training by utilizing SSGs, but these activities require investments. Only procurement do not guarantee usage. During the pre-implementation phase, the technology has to be adjusted to local needs. These needs have to better inform constructing scenarios and placing SSG training in local education plans. Here, the instructors play a vital role since they should be involved from the start to support engagement for SSG training but also to reduce the risk for false expectations. Their SSG competence is different from general digital literacy, it involves setting correct requirements for simulations, adjusting SSGs to local needs and scenario development.

Already prior to procurement, organizations need to realize that they should take an active part in adopting the SSG training to their own circumstances and current and future needs. They need to address the internal needs and requirements for adoption, learning and allocation of resources for introduction, which the developer (SSG vendors) cannot deliver when the sales is made. They cannot be aware of and deliver solutions for all internal requirements. On the other hand, the user organizations cannot predict all the effects before it actually having been used in their own settings. This may result in unnecessary waiting, delays or failures of SSG utilization. Overcoming this deadlock is essential, since it limits both use and further development and thereby impeding a potential beneficial utilization of available SSGs. Today SSG is not a "magic bullet" solution, which per se contributes to learning after procurement. Here, the suggestion is to consider SSGs as new mini-systems in development which contribute to developing organizations (see Figure 4). This suggestion is based on Hevner's (2007) argumentation for design science. Since SSGs needs to be integrated as a process in organizations, educational plans, training situations in order to produce practical and theoretical values, this approach may point to certain difficulties to overcome. It shows that during procurement the application domain is seldom described. While problems and opportunities are defined the training values cannot be, the users are not aware on possible scenarios. During pre-implementation certain aspects necessary to design and build new scenarios are missing. To produce added (for the user organizations) practical values issues about the rigor, and how values contribute to the actual knowledge would be necessary.

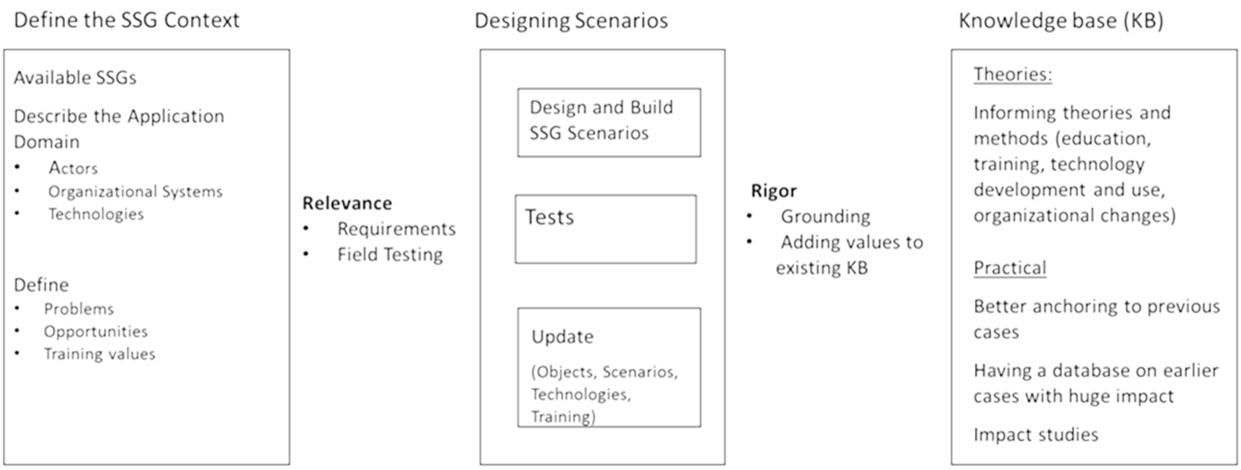

Figure 4. Treating SSGs in organizations is a process that should begin with describing application domain and defining problems, opportunities and training values to be solves (modified from Hevner, 2007) during pre-implementation.

As an example, a critique against using SSG was experiencing its low quality, comparing with current computer or video games. This would not be possible if the relevance of scenario design (middle box) would be described for the user organizations (left). The low fidelity of the SSG technology expressed in this study as revealed by the obstacles within attitude, expectation and competence, could be overcome if the training scenarios were perceived as more authentic and trustworthy. One way to achieve this, we propose, is to base the SSG scenarios on real, authentic data from previous incidents Rescue services are required to document every incident in standardized event reports. These previous event reports can be digitally analyzed and used for generating scenarios, which are not only realistic but based on events that evidently have taken place. Merely the knowledge that these scenarios are “based on true stories”, a type of “documentary simulations”, ought to affect the reliability of the situation, that is more than visual fidelity. In this way, the simulations could be seen as an illustrated true narrative, rather than an attempt to simulate complex unlikely situations. These scenarios can then be used for discussing how the incidents progressed, what decisions were taken, and what the alternative ways of action are. The idea is to spread previous firefighter experiences in a more authentic way to learners and raise a scenario-awareness among these.

As we showed, information about the successful introduction of technologies differs between the different organizations. They have different motivations to begin to use SSGs, different approaches to handle the training process, and different support for this. However, further investigation into linking SSG introduction to digital competence in an organizational context is needed.

ACKNOWLEDGMENTS

We thank Lena Pareto, Katalin Levai, and Lars Bråthe for the advices and comments when initiating the study, and the interviewees and people allowing us to participate to typical training situations, and MSB for funding the study.

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Smoke dynamics in compartment fires: large scale experiments and numerical simulations

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ABSTRACT

Today, during compartments fire, the decision-making of the rescue teams is mainly based on human decisions, which are the results of gathered experiences. However, a perfect knowledge of the situation, its evolution over time and the dangers that may appear is impossible.

The transition between a localized fire and a generalized fire can take several forms. One of the most important vectors in the propagation of combustion for compartment fires is smoke due to its high temperature and the large amounts of energy it contains. Despite its extreme danger, smoke remains important to study because it convey valuable information, especially on the appearance of thermal phenomena feared by firemen. To carry out this study, a large scale experimental cell is used. A burner fueled with propane produces hot fumes in a so-called "real fire" configuration. All the measurements carried out are compared with LES (Large Eddy Simulation) simulations of the experiment using FDS.

The numerical component allows defining scenarios (fire fully developed, fire under ventilated ...), which are verified by the experiments.

The dual competence numerical /experimental data is essential in this type of study since the experimental data suffer from a lack of resolution (spatial, temporal) but nevertheless represent information necessary for validating the codes.

Keywords

Compartments fire, numerical simulations, FDS, smoke dynamics.

INTRODUCTION

Nowadays, during a fire intervention, the decision-making of the emergency services is mainly based on rapid disaster analysis. The analysis is coming from the experience gained over the years but also during the training given in the Firefighter fire simulators.

However, this type of analysis does not allow for a complete knowledge of the disaster since it is mainly based on empirical knowledge. The evolution of fire, the appearance of a secondary focus or certain thermal phenomena, particularly feared by the rescue services are difficult to predict with accuracy. These are all factors which mainly lead to fatal accidents.

Indeed, the rescue teams are regularly victims of thermal phenomena that are difficult to predict. Every year firefighters die on interventions where the fire degenerates into flashover or smoke explosion (backdraft). We remember in particular the explosion of Neuilly sur Seine in 2002 when five firefighters of Paris died during a priori banal room fire.

During a fire, two thermal phenomena representing a major danger for rescue teams may occur:

- Flashover. This phenomenon occurs when the combustible surfaces, heated by the fumes or the radiation, are spontaneously ignited and simultaneously the pyrolysis occurs. To observe this phenomenon, the supply of oxidizer must be sufficient;

- The explosion of smoke is backdraft. This phenomenon appears during under ventilated fires lack of oxidizer. Very high temperatures are also observed. When an opening is created, the sudden intake of fresh air and the exit of hot fumes cause a mixture that ignites spontaneously. The increase in pressure due to this reaction causes a violent explosion outside the premises concerned.

In order to optimize and secure the intervention of rescue services, knowledge of fires, their dynamics and the danger they represent is a major asset. One of the main aspect remains in determining the smoke dynamics at the openings, where fresh air, hot fumes mix together. For this, we are interested in the theory of plumes. Theoretical knowledge on these phenomena will make it possible to improve the understanding of smoke flows, in particular at outlets (Morton et al., 1956).

The direct link between the mass of the flow and the air entrained by the plume justifies our interest in this work. Indeed, a good physical approach of the plumes will allow a better understanding of the smoke in fires (Heskestad, 1998).

The physicochemical processes governing compartment fires and associated thermal phenomena are extremely complex. Fumes play an important role in the spread of fires. As a result of convection and pressure fluctuations, they spread through all kinds of ducts (corridors, stairwells, elevator shafts, technical ducts, sanitary ducts, etc.).

Due to their very high temperature, smoke which enters a fresh volume can ignite spontaneously in contact with air or ignite the fuel present. This situation can lead to the generalized fire of a building from a focal point located in a single volume (Francis and Chen, 2012).

Unlike other intervention techniques, technological means to avoid this type of accident have received little attention. Due to difficult operational environments, research projects have been launched to allow firefighters to improve their spear techniques, particularly in the attack on semi-confined fires. This is the case of the PROMESIS research program, which brought together a consortium of professionals and academics to enable intervention teams to adapt their attack techniques. You et al. (2010) have defined the effective pulse time, size and flow rate in the control of confined fires.

In this context, the ANR program FIREDIAG has the objective of setting up a decision support tool. Indeed, this research project is based on the information conveyed by the fumes. The objective is to provide the fire officer a technological tool to analyze the situation and help decision-making in real time. The difficulty of developing these tools remains on the complexity of the phenomena involved in compartment fires (combustion, explosion, smoke flow, etc.). Numerous parameters have to be taken into account (temperature, gas flows, heat exchanges, etc.) but are difficult to measure (sensors, detectors, etc.). Moreover, the information received by the intelligent and communicating system must be able to be transmitted in order to be construed quickly and efficiently.

To sum up, this type of technology could include:

- Improve the speed of the detection of a disaster;
- Give information on the nature of the fire, its development speed in order to adapt the emergency means to the fire progression;
- Monitor the evolution of the disaster in real time, particularly in terms of propagation or the appearance of thermal phenomena.

In order to carry out this study, an experimental cell is installed on the firefighting site of the Seine Maritime's firefighters. This platform which size is 6m long, 2.59m high and 2.45m wide allows to produce hot fumes in a so-called "real fire" configuration using a propane fueled burner. Fumes are analyzed using non-intrusive measurement techniques such as PIV for the velocity fields. Large velocity fields using PIV in confined environments is a complex task (Hou et al., 1996). Subsequently, tests have already been carried out at the level of the fireplace (Tieszen et al., 2002), and then at the level of the doorways in the PIV Fire project carried out by the IUSTI laboratory and the Cadarache IRSN (Koched et al., 2012). These studies showed that PIV allows very reliable and less intrusive measurements of speed than bidirectional probes. However, these tests were conducted with thermal powers lower than our experiment (21,7kW). Measurements by PIV (large fields) will be done and compared to LES simulations of the experiment (with Fire Dynamics Simulator, Fire Dynamics Simulator Technical Reference Guide Volume 1, 2, 3: Mathematical Model, Verification, Validation, McGrattan et al., 2007). However, due to inherent issues with large scale PIV, which are still under process, the present study mainly focuses on temperature measurements in the experimental. The experimental data are compared with simulations using FDS code.

Experimental test

To carry out this project, the different partners have established the specifications of an experimental unit which is close to real fires. Therefore, the analysis of thermal phenomena studied in the experimental test bench is likely to be found by firefighters during their missions. This cell is actually made of two maritime containers set up perpendicularly and called respectively "measure cell" and "test cell", Figure 1.

Figure 1: Picture of the experimental cells, Top view

The standard size of the maritime containers is 6m long, 2.59m high and 2.45m wide. Initially, these structures have emerged as training tools in rescue services in order to train firefighters to detect the signs of thermal phenomena and to fight effectively against them. Moreover, the volume of these containers is close to that of a room of standard flat, approximately 15m ².

To reproduce the conditions of a fire, a propane fireplace is installed. The latter consists of 36 burners spread over an area of 1m² that can reach a power of 1MW and a temperature of 1000 ° C, Figure 2.

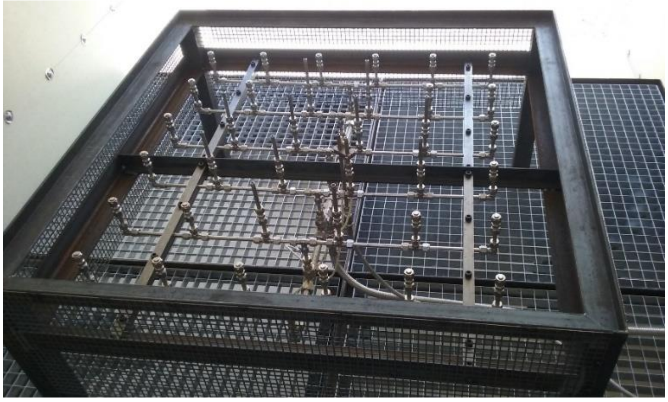

Figure 2: Picture of the 36 burner arrangement for the 1MW burner

Although propane produces only a small amount of soot compared to real fires, this type of burner has been chosen because it has the advantage of perfectly controlling the power. Moreover, the reproducibility is ensured. To produce soot that is missing from the fire, ethylene can be injected into a small amount in the burner.

Due to the high temperatures that are reached during the measurement campaigns, insulation has been an important step in the design of the measurement cell, Figure 3. It is composed as follows:

- Blocks of cellular concrete with a thickness of 70mm on the ground;
- Rock wool and mineral wool installed on the ceiling;
- Mineral wool and vermiculite plates (30mm) on the side walls.

Figure 3: Picture of the experimental cells, inside view

To study different scenarios, the volume of the test cell can be modulated thanks to a removable wall. Its optical access of 1m ² in quartz allows the installation of optical laser based measurement techniques directly in the axis of the fireplace. In addition, the hot gases can flow outside the container through two outfalls. The interaction between the ambient air and the hot gases will be studied, in particular by using bidirectional probes and PIV technique at the exit.

The test cell is equipped with 2 shafts of 10 type K thermocouples, an opacimeter and a gas analyzer, making it possible to measure CO and O2 concentrations. The measurement cell is equipped with 2 quartz windows to carry out velocity fields and scalar field measurements by large scale PIV. The flow dynamics and the scalar fields will be studied on the central horizontal and vertical planes as well as at the exit, just below the ceiling.

Numerical simulations

For the numerical simulations, the calculation code Fire Dynamics Simulator (FDS) (Desanghere, 2006), has been retained. Widely used in fire safety engineering, this code allows obtaining a faithful representation of the fire dynamics

In order to optimize the reliability of this software, meshes of 5cm are used for the simulations presented later. A sketch of the numerical design is shown in Figure 4. For the experimental cell, this represents slightly more than 285,000 nodes. To optimize the computation time, the simulations are carried out using a supercomputer attached to the laboratory, CRIAAN meso calculation center.

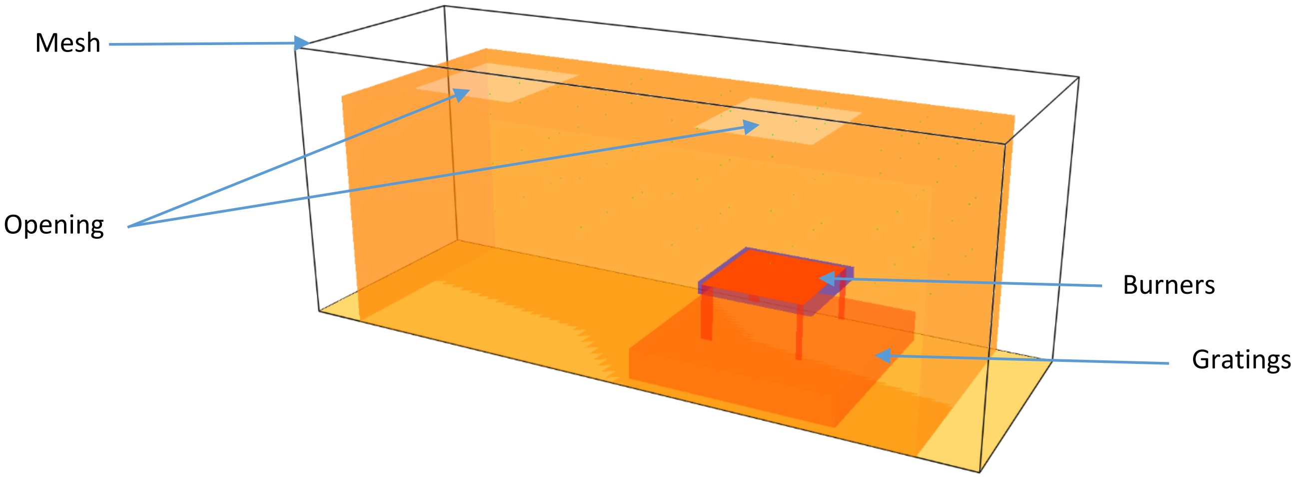

Figure 4: Modeling FDS of the cell

The entire set of FDS results is post processed using the Matlab software.

For this study, four main configurations are chosen:

- Scenario 1: Large volume, an open outlet;
- Scenario 2: Large volume, two open outlets;
- Scenario 3: Small volume, an open outlet, Figure 5;
- Scenario 4: Small confined volume.

For all the current simulations, a power of 500 kW is applied. For the different scenarios, the firepower can be modified. This is the case of Scenario 1 or calculations are carried out up to 1MW.

In order to compare the numerical simulations with the first experimental measurements, sensors are placed in the same places, numerically and experimentally. The position of the sensor for case 3 is given in Figure 5.

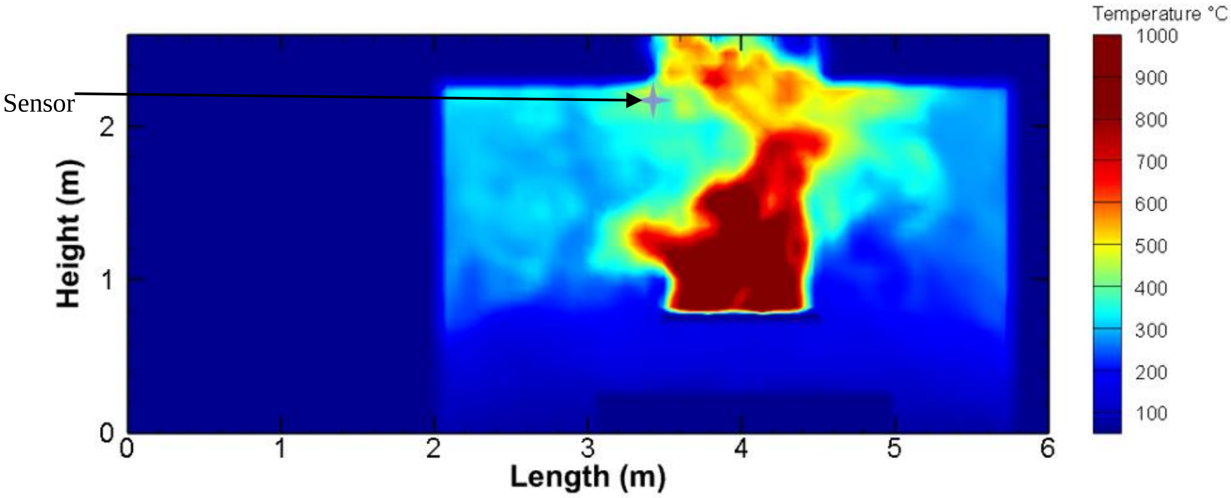

Figure 5: Modeling of the temperature of scenario n ° 3 (° C)

In addition, other numerical simulations are carried out in the large volume configuration with an open outlet. The purpose of these simulations is to observe the behavior of the fire with an opening serving both for the entry of fresh air and for exiting hot fumes. Subsequently, these test cases are reproduced in the experimental chamber in order to verify the numerical results. The simulation software FDS is not verified in this type of configuration (under ventilated), this comparison between numerical and experimental measurements is therefore very interesting for the research community fire.

RESULTS

Numerical scenario

The following section shows the development of the fire at 500 kW considering case 1. The fireplace is located to the right of the cell with the outlet open to the left. The conditions at the walls are considered adiabatic. For this simulation, the mesh is also made with cells of 5cm x 5cm. An instantaneous temperature field at time t=50 after the fire starts is shown in Figure 6.

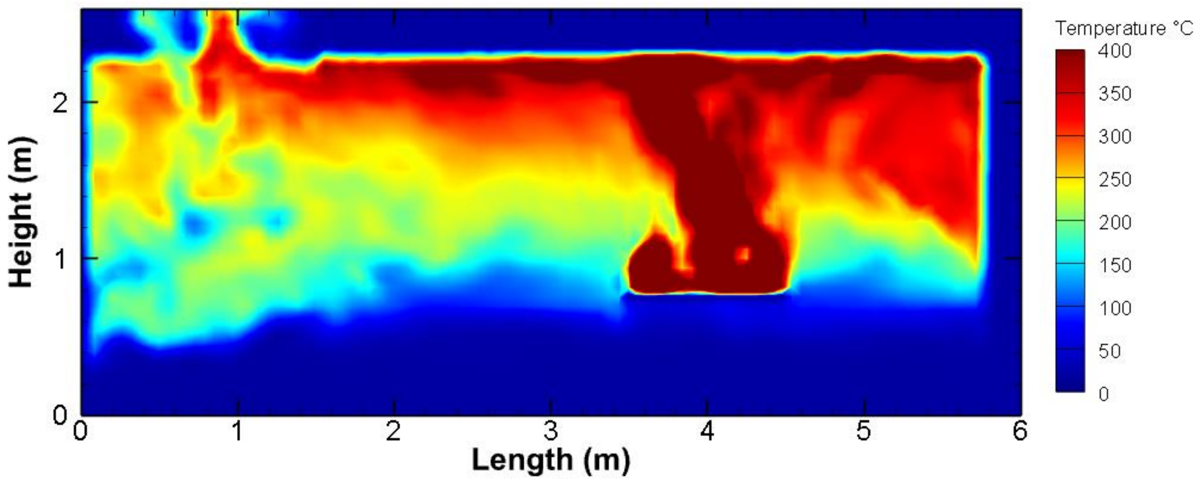

Figure 6: Modelling of the temperature of scenario n ° 1 at 50 seconds

At 50 seconds, the fire develops normally. There is a layer of stratified hot flue gases in the upper part of the volume concerned. At 300 seconds, Figure 7, the fire behavior is completely different. A large part of the oxygen of the volume has been consumed. The initial focus is no longer localized at the burner Indeed, it is observed that the flame moves at the outlet position. On the modeling, the flame position is highly fluctuating. This phenomenon represents the alternation of fresh air intake and evacuation of hot smoke.

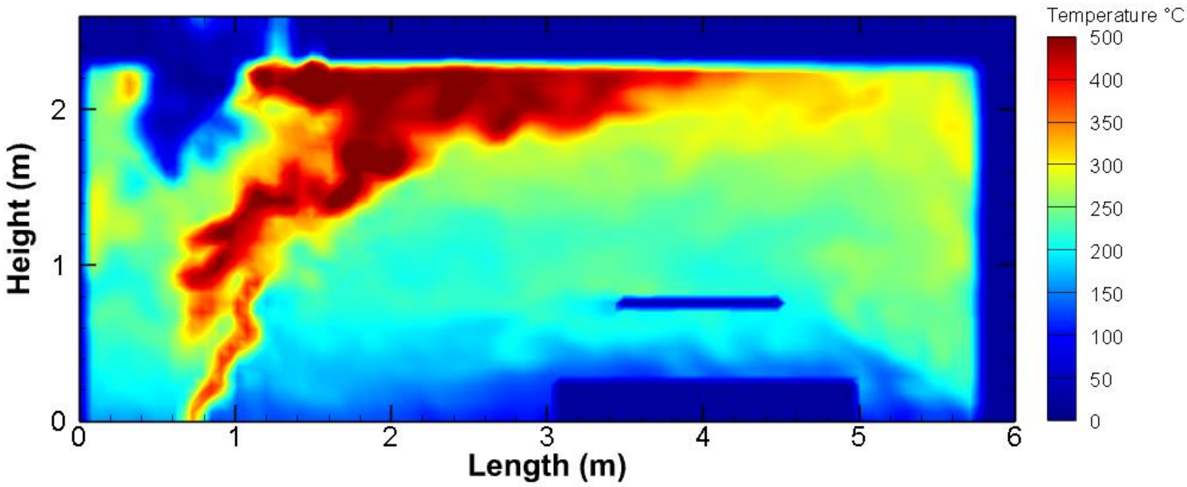

Figure 7: Modelling of the temperature of scenario n ° 1 (° C) at 300 seconds

Averaging the temperature field, Figure 8, we can observe that the flame is mainly positioned at the outlet. Where there exists a. In a under ventilated fire situation, this phenomenon is explained by the lack of oxidant (here the oxygen) necessary for the home to develop properly.

Indeed, when the fireplace lacks oxygen to burn the whole of the fuel present, the pressure in the enclosure decreases and will allow fresh air to enter. This fresh air inlet will restart the combustion and increase the pressure of the volume again (through the increase of smoke) which will lead to a release of hot fumes.

This phenomenon is repeated until the fuel is exhausted. It is illustrated in Figure 8 where a higher temperature is observed at the outlet as well as an absence of flame on the fireplace. However, these numerical observations remain to be verified with the experimental one. Indeed, the FDS code is limited when modeling under ventilated fires. It tends to overestimate the appearance of ghost flames (flame that comes off the burner to use the oxidizer of the room). Although this phenomenon is scientifically possible, the focus could just as well be extinguished and the flame would disappear.

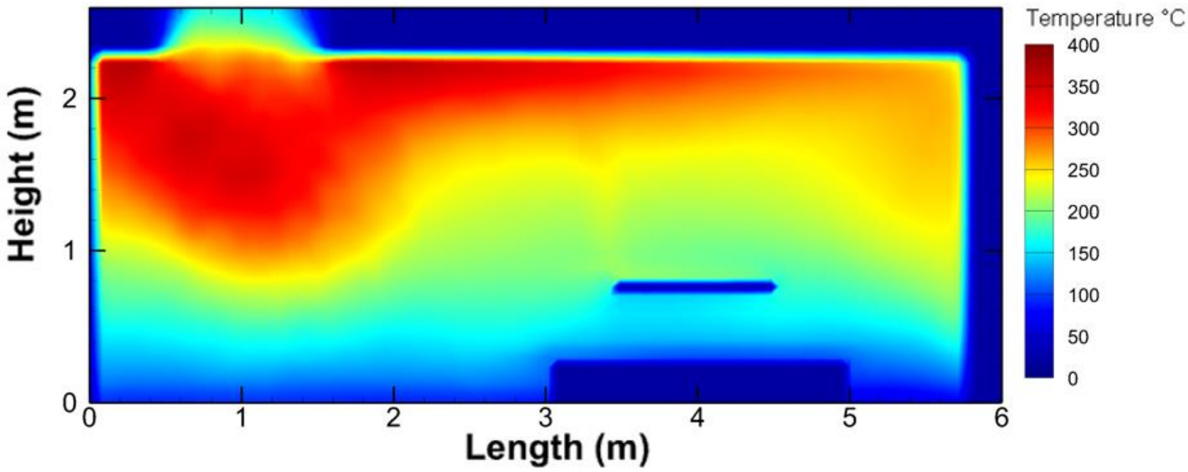

Figure 8: Modelling of the average temperature of scenario n ° 1 (° C)

The following section shows the development of the fire at 500 kW considering case 3. The fireplace is always on the right. The volume considered is the small volume (removable wall in place) with the outlet open. As for the previous simulation, the conditions at the walls are considered adiabatic. The mesh is also made with cells of 5cm x 5cm. An instantaneous temperature field at time t=50 after the fire starts is shown in Figure 9.

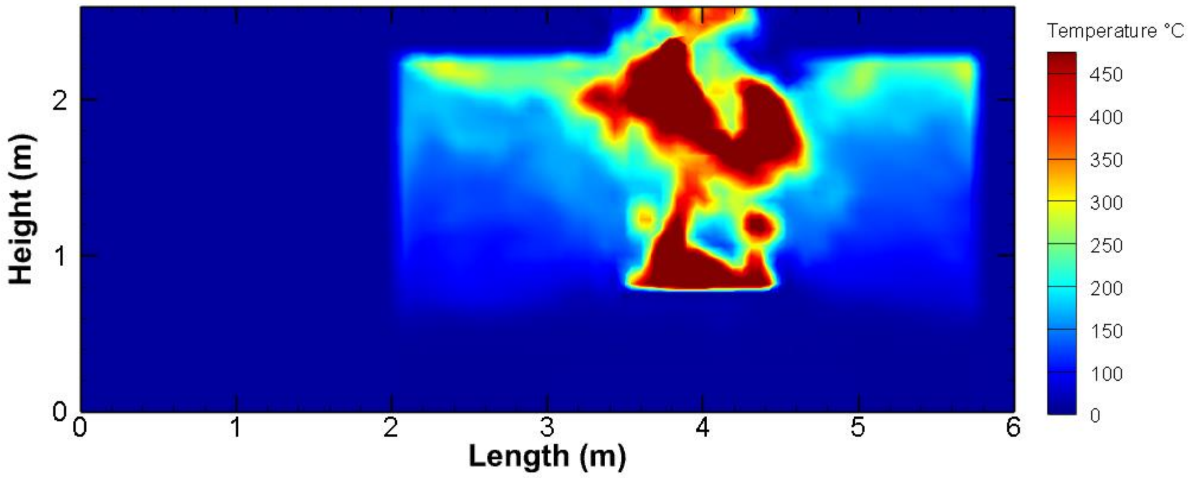

Figure 9: Modelling of the temperature of scenario n ° 3 at 50 seconds

At 50 seconds, the fire develops normally. Unlike scenario 1, the hot gases are evacuated and very little stored in the volume. This can be explained by the direct presence of the outlet above the fireplace, thus avoiding the displacement of the fumes in the experimental cell. At 300 seconds, Figure 10, the fire is quite similar. The layer of hot smoke is more developed. It is lower in the volume and makes it possible to demonstrate a clear stratification of the fumes.

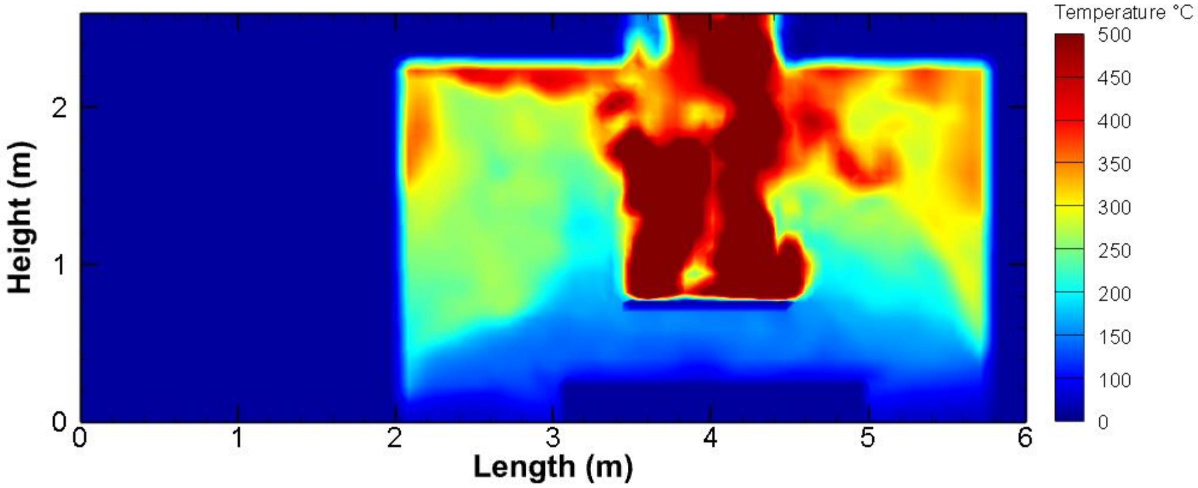

Figure 10: Modelling of the temperature of scenario n ° 3 (° C) at 300 seconds

The intermittent phenomenon alternating between fresh air intake and outlet of hot fumes is also present. However, due to the volume configuration, the fireplace is much less ventilated. There is therefore no ghost flames as observed in case 1.

Averaging the temperature field, Figure .11, we can observe that the temperature field is close enough to what has been shown in Figure 10. The smoke plume and the stratification of the hot gases are easily observed. This type of fire development is common in properly ventilated fires.

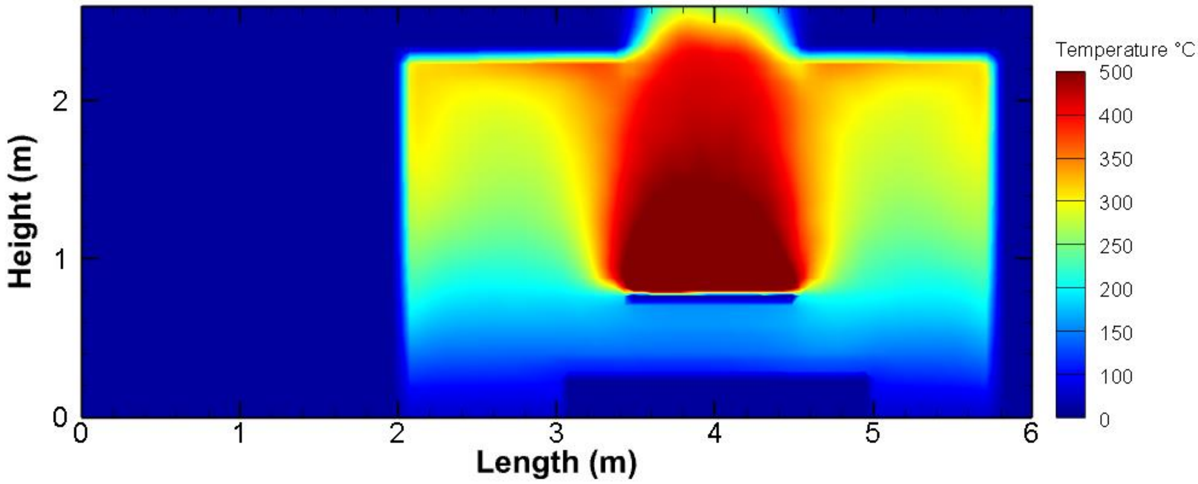

Figure 11: Modelling of the average temperature of scenario n ° 3 (° C)

Experimental test

In order to validate the numerical results presented above, an experimental test was carried out under case 3, namely, small volume, 500 kW, open outlet. The 36 burners were turned on. The thermocouple taken into account for the results below is placed in the same place as the digital sensor, Figure 5. Figure 13 shows the fireplace with the 36 burners burning. However, for better modularity, the number of burners can be changed, thus modifying the power flux-density.

Reference
Thermocouple

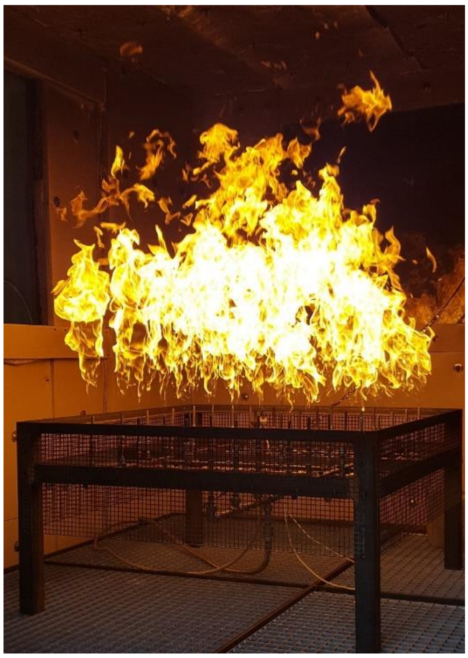

Figure 12: Test cell

Figure 13: Fireplace 500kW, 36 burners

Following this test, the following temperature against time curve is plotted, Figure 14. The experimental curve is represented in red, the adiabatic in pink and the curve in the normal conditions FDS in orange.

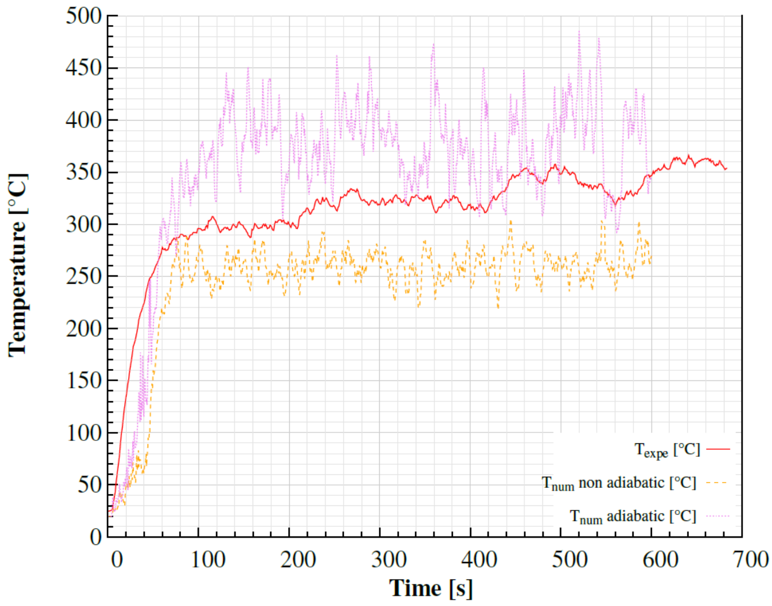

Figure 14: Curves to 500kW

From the simulations, adiabatic and real configurations are tested. Compared to the numerical values, Figure 14, it can be observed that the three curves are very similar. However, the adiabatic numerical values (pink curve) are slightly higher than the experimental values, whereas the non-adiabatic case is under estimating the temperature. However, good agreement is observed. On the experimental curve, we can observe that the steady state is not reached, in contrast to the numerical simulations presented above. On the other hand, the rise in power is underestimated in numerical terms. In order to get closer to the experimental, improvements have to be made on numerical simulations.

Figure 15 shows the evolution of the temperature as a function of time. The red curve always represents the experimental value. The blue curve represents the result of the improved numerical simulation. In order to get closer to the measured temperature, three improvements were made.

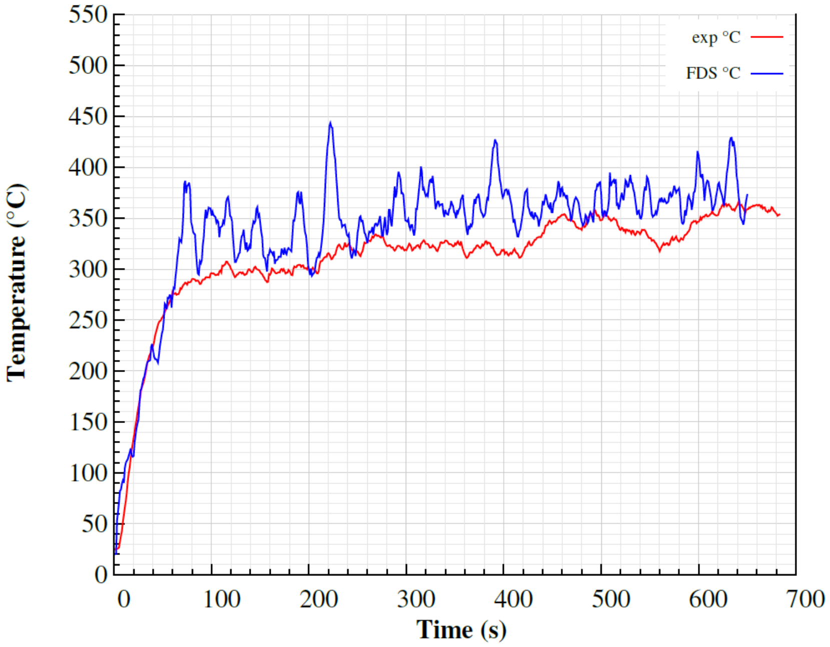

Figure 15: Experimental and modified curves to 500kW

Firstly, the ramp-up has been reduced. The fuel being propane, the combustion is extremely fast. Secondly, an opening in the lower part was created. It aims to simulate the leakage observed on the cell during the tests. Thirdly, the digital firepower has been adapted. Indeed, for reasons related to the experimental installation, the power of the fireplace cannot remain constant at 500kW. Propane bottles are frozen and the power is changed. After checking, the firepower is closer to 460kW. The numerical simulation presented here was carried out with this value.

Following these improvements, there is a very similar increase in power in experimental and with numerical simulation. The gap between the curves and reduces. Moreover, it can be seen that the digital curve does not reach the steady state.

CONCLUSION

To conclude, the first numerical and experimental results are conclusive. Indeed, it is observed that the temperature profiles obtained are quite similar. Technical points from the CFD need to be slightly adapted. Other measures will soon be initiated in order to compare other physical quantities and thus further refine the numerical model including speed measurements by PIV. These measurements will make it possible to compare the numerical and experimental results for the speed, another significant physical magnitude for the compartment fires. The series of experimental tests will allow to verify the numerical results obtained for configurations under ventilated and will thus validate the calculation code FDS. In addition, with the aim of checking the code, scenarios with different firepower (up to 1MW) will be simulated and experimentally tested. In addition, measurements of opacimetry and a gas analyzer will complement the experimental cell. These measures will also be used to compare numerical values and thus enhance the reliability of the code.

ACKNOWLEDGMENTS

The financial support of the Agence Nationale de la Recherche (ANR) – FIREDIAG project – and the CRIANN for the simulation support are acknowledged. The fire district SDIS76 is also acknowledged for its support concerning the experimental setup

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A general system architecture and design for the coordination of volunteers for agile disaster response

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ABSTRACT

In the recent decade the evolvement and widespread success of new technologies in particular in the field of computing power, network bandwidth, mobile networks and wearable devices have prepared the foundation for completely new approaches in crisis management. Currently, we are at the edge that such new technologies for crisis management are becoming a real and practically applicable option, e.g. in the field of alerting, crowdsourcing, and crowdtasking. In parallel, we witness in the recent years that citizens are more and more willing to help during crisis and disasters, thus providing a large – yet unused – potential for agile support in disaster preparation and response. In many disaster situations the emergency personnel reach the limits of their capabilities. In particular during the isolation phase the support of such volunteers can be a valuable benefit for disaster response. With the help of new technologies crisis management can provide current on-site information via mobile devices in real time as well as organize and coordinate the activities of the volunteers at specific locations. In this paper we present the results of the research project ENSURE: a general architecture and a system design for the coordination of spontaneous volunteers for agile disaster response. With the expected broader implementation of such systems in disaster management in the future it is inevitable to elaborate such common technological foundations for practical mass applications.

Keywords

Crisis and disaster management, Response, Alerting, Crowdsourcing, Crowdtasking, Volunteer system, Architecture, System design, System test

1 INTRODUCTION

In classical crisis and disaster management the role of volunteers is mainly limited to the work of volunteer organizations or to the appointment of citizens to support authorities and response forces in cases of large scale disasters. The increasing occurrence of so-called unbound volunteers in recent disaster cases, such as during the flooding at the river of Elbe is currently a major challenge for official disaster response forces but bears at the same time a wide opportunity to massively potentiate certain disaster response actions. In recent years, more and more citizens spontaneously offer impromptu aid when the emergency personnel cannot respond immediately

(Schweer et al., 2014). The challenge is that such unbound volunteers are currently not coordinated and aligned with the strategy and actions of the official response forces. This missing coordination can lead to frustration among the volunteers (Kircher, 2014), may even result in unintentional damages (Schorr et al., 2014) or even to the aggravation of disaster situations e.g., when the volunteers actions contradict with actions of response forces, or when volunteers put their lives or of others in danger. On the other hand, in many disaster situations the emergency personnel reach the limits of their capabilities and in particular during the isolation phase when the response forces have not reached the area of impact yet the support of such volunteers can be a valuable benefit for disaster response. Professional crisis management must be able to integrate and coordinate volunteers in order to benefit from their support and avoid damage and confusion due to poor coordination. Furthermore, it can provide the necessary flexibility for agile crisis and disaster management by overcoming the problem of (re-)allocating response forces in time at upcoming hotspots by using volunteers that are already there.

At the same time the necessary development and widespread availability of new technologies in the field of computing power, ubiquitous connectivity, mobile devices and applications provide today a practically applicable basis for supporting such complex coordination tasks. The wide adoption of mobile devices (smartphones, tablets etc. with the capability of geo-location) and the spread of the Web 2.0 philosophy on the web and in the general public created suitable conditions for establishing the idea of the necessary new approaches in a wide range of application scenarios successfully. These interactive, collaborative, and mobile approaches can help to effectively involve spontaneous unbound volunteers in disaster management in case of an emergency (Reuter et al., 2012). In the field of early warning and alerting the use of mobile infrastructure has become a key technology for effective alerting in particular for individual information needs and response capabilities (Meissen and Fuchs-Kittowski, 2014). Web 2.0 has created concepts of participation, such as crowdsourcing (Howe, 2006), which have facilitated the engagement of volunteers and which have successfully been used in crisis management (Kaufhold and Reuter, 2014; Schimak et al., 2015). In addition, the widespread use of mobile devices among the population offers a high potential to change the way of communicating with citizens in the event of a disaster, and to simplify the participation of the citizens as active volunteers (Reuter et al., 2014). With the help of these new technologies, crisis management can provide current on-site information via mobile devices in real time as well as organize and coordinate the activities of the volunteers at specific locations.

Based on a) the need for volunteer support in certain disaster situation b) the increasing willingness of citizens to support ad-hoc response actions, and c) the availability of necessary new technologies we have developed and practically tested a general approach for volunteer coordination systems in the ENSURE project which results are presented in this paper from a technical point of view. So, it is important to state that organisational, legal, sociological and psychological aspects of volunteer coordination are not the focus of this work. We do concentrate on the technological aspects of providing the necessary functionality through a general, flexible and fast performing system architecture that makes full use of current technologies.

The paper is structured as follows: Section 2 presents related work in terms of relevant technologies and related projects. In Section 3 the functional and non-functional requirements are described based on the general use cases for the envisioned solution. Section 4 shows the general reference architecture and its components. Section 5 describes the used implementation and the technology for a pilot system. Section 6 shows the results of the evaluation based on field test. Finally, in Section 7 we draw the conclusions of the presented approach and describe further research directions.

2 RELATED WORK

2.1 RELEVANT TECHNOLOGIES

In order to realize a volunteer coordination system it is generally necessary a) to actively inform the volunteers in time and at their location with individual messages b) to receive information from each volunteer, and c) to support specific tasks of each volunteer. In the context of crisis and disaster management we find the existing technical foundations for such solutions in the field of a) mobile (targeted) alerting systems, b) mobile crowdsourcing/sensing, and c) mobile crowdtasking. In our approach for a general volunteer system we combine existing technologies used in these approaches:

Mobile alerting: Such systems have to be distinguished between broadcast-based alerting approaches (how it is performed e.g. by cell-broadcast systems like in the Netherlands or US) and personalized alerting systems with the ability to address individuals or certain groups with different alert messages (how it is performed e.g. by the App-based public alert system in Germany (KATWARN, 2017)). Along with the increasing coverage provided by new ICTs in the last decade, in particular web technologies, mobile devices and individual messaging, the foundations have been laid for the development of new personalized mobile warning systems. The initial steps towards this type of targeted alerting were described in (Meissen et al., 2014). Also, in (Meissen et al., 2014) a first general reference architecture for personalized alerting system is presented that served as a basis for the implementation of the KATWARN system in as large scale alert system for the public with currently approximately 3 million users (KATWARN, 2017). This system is also providing the basis for the alerting and profile management of the reference architecture and implementation of the general volunteer system presented in this paper.

Mobile crowdsourcing/sensing: Our understanding of the notion 'crowdsourcing' is that a group of people voluntarily collects and shares data and information using widely available mobile devices (smartphones etc.) or/and web applications, where this data is processed and provided via a data-sharing infrastructure to third parties interested in integrating and remixing this data. Concrete projects and applications in disaster management are for instance: InSTEDD, GeoChat, FrontlineSMS , RapidSMS, Outbreaks Near Me, Ushahidi. InSTEDD is a suite of open-source software tools that aims to achieve faster and more coordinated responses to disease outbreaks and natural disasters described in (Fuchs-Kittowski and Faust, 2014). This type of involvement, in which simple, digital information tasks are performed on-site by volunteers, can be described as "Mobile Crowdsourcing" (Fuchs-Kittowski and Faust, 2014) (or "Mobile Crowdsensing", if data is captured using the built-in sensors of the mobile devices).

Mobile crowdtasking: Is a sub-form of mobile crowdsourcing, in which volunteers undertake special physical tasks (such as filling sandbags, providing first aid to injured people, protecting cultural assets, securing dangerous places, etc.) and report on them if appropriate. Two forms of mobile crowdtasking can be distinguished based on the task distribution scheme (Fuchs-Kittowski and Faust, 2014), with one approach being an independent, autonomous task selection and the other a coordinated task assignment. In the first case, the volunteers choose their own tasks from a pool of globally available tasks. In the second case, qualified volunteers are efficiently given appropriate tasks with the aim of fulfilling the objectives of the application as best as possible. In a narrower sense of the term, only the subcategory in which the volunteers are not addressed as a group, but rather assigned individual tasks, is referred to as crowdtasking (Neubauer et al., 2015). The potential of crowdtasking systems remains largely untapped with only a few examples of such systems currently in use to assign real, physical tasks to volunteers (e.g., filling sandbags).

From previous research in mobile crowdsensing and crowdtasking we adopt some general component schemes and approaches for our solution which are incorporated into the general alerting reference architecture used in KATWARN.

2.2 Related Projects For Volunteer Integration

Current projects for an integration of unbound volunteers are Hands2Help (Hofmann et al., 2014), AHA (Detjen et al., 2015), and KOKOS (KOKOS, 2017). There are already some projects based on practical experience such as Ready2Help (Schmidt et al., 2016), ZUKS (ZUKS, 2017), and Team Österreich (Team Österreich, 2017) aimed at the coordinated involvement of volunteers. Within these systems we witness a shift from technically simple solution based mainly on web portals for registration and SMS/email for activation towards more sophisticated approaches with advanced coordination and feedback functionalities based on volunteer apps. Related volunteer systems such as FirstAED (FirstAED, 2017), instantHelp (instantHelp, 2017), or Pulsepoint (Pulsepoint, 2017) (notifies a registered user of an accident in the area according to the user's skills) are also aimed at involving and coordinating volunteers, but they are mainly used for ad hoc lifesaving, i.e., they are specially designed for first aid, and not common tasks in crisis management.

All these approaches so far have the following points in common: they provide methods and tools to recruit a greater number of volunteers, mobilize and activate them when needed, and coordinate their activities. To achieve this, a specific control system is required in order to distribute the tasks to suitable volunteers. A mobile app is also necessary for the volunteer to receive the tasks, coordinate with others, and get involved. However, what is missing is a general reference architecture for such systems and evaluation results for the technical aspects of the system from field studies, which is the main contribution of this paper.

3 REQUIREMENTS

A major part of the interdisciplinary research in the ENSURE project aimed at the identification and classification of appropriate disaster scenarios in order to derive the different requirements for the volunteer system. Whereas from a crisis management the identified scenarios differ based on a variety of significant parameters from a technical system point of view the following three general application categories were of major relevance:

Application Category 1: Long lead-time scenarios for crisis management. In these scenarios we have a long lead-time (days) until the tasks/actions of the volunteers have to be performed. They have in common that we usually have scenarios were professional forces are involved and tasks are preformed under direct control or jointly together. These scenarios are occurring mainly in the preparation and recovery/mitigation, and only partly in the response phase (e.g., during disasters with longer impact time). A typical example for such a scenario in this category is sand bag filling in order to prepare for long-term flooding. From a functional point of view in such scenarios the location of the volunteers is not a key parameter for activation as there is usually enough time to organize transport facilities. However the profile and abilities of each volunteer can be a crucial parameter for activation selection. From a non-functional point of view the performance requirements for such as system have to possibly take a large number of volunteers into account that have to be activated and coordinated. However, most information tasks in these scenarios are not time critical.

Application Category 2: Short lead-time scenarios for crisis management. In these scenarios we have a very short lead-time (hours, minutes) when the tasks/actions of the volunteers have to be performed. They have in common that we usually have scenarios were emergency forces are not yet involved and tasks are preformed in the isolation phase. These scenarios are occurring solely in the response phase. Typical examples for such scenarios in this category are evacuation and first aid scenarios.

From a functional point of view in such scenarios the location of the volunteers is now a key parameter for activation as only close by volunteers can react. From a non-functional point of view the performance requirements for such as system have to send out tasks in almost real-time as every second counts and the robustness of the system has to be on the highest possible level. However, the numbers of volunteers to be informed and coordinated are considerably lower in comparison to category 1.

Application Category 3: Short lead-time scenarios for emergency management. These are scenarios similar to category 2 but for daily applications in emergency management. A typical example is a first-aid scenario with activation of volunteers to use a defilibrator before an ambulance arrives. We have taken such emergency management scenarios into account since it is an important motivation and training factor for volunteers to be activated more frequently than only for major disaster scenarios that possibly occur every decade. Functional and non-functional requirements are similar to the ones in category 2. For the performance aspects the requirements of a higher activation frequency and a 24*7 operation has to be taken into account additionally.

Beside the differences pointed out above the main functional requirements all categories have in common for the effective recruitment, management, activation, and coordination of volunteers are:

- Volunteer registration
- Volunteer profiling
- Volunteer selection
- Alerts and task activation
- Volunteer feedback

In the ENSURE implementation, the system distributes help requests or alert in the event of a hazard or emergency. These requests or alerts are delivered to the volunteers via a mobile app. Volunteers can be activated in two ways: Firstly, the control system can trigger a regional alert to all volunteers in a given area. With this type of alert, volunteers receive a request if they are in the immediate vicinity of the emergency based on their current location (for application category 2+3). Alternatively, volunteers can receive topic-based alerts by subscribing to a certain topic, e.g., “Flooding 2013 – Dresden” or can be selected by their profile (for application category 1).

The general non-functional requirements were postulated with respect to established requirements for IT applications in disaster management in the literature (Mauthner et al., 2015), namely:

Efficiency and safety: the volunteer system shall be applicable for mass application with hundred thousands of users and capable of providing tasks and alerts in a short time without demanding massive hardware investments. All personal information processed by the system shall be protected from misuse.

Clarity and usability: the volunteer system shall be easy to use without training. All information provided by the system in particular alerts and tasks shall be clearly understandable.

Reliability and availability: the volunteer system shall be robust in operation with a minimum of failure and maintenance time.

4 ARCHITECTURE

Figure 1 shows an overview of the general architecture for volunteer systems developed in the ENSURE research project based on the envisioned functional and non-functional requirements. The later had a strong influence on the architecture in particular to ensure efficiency, safety, reliability and availability.

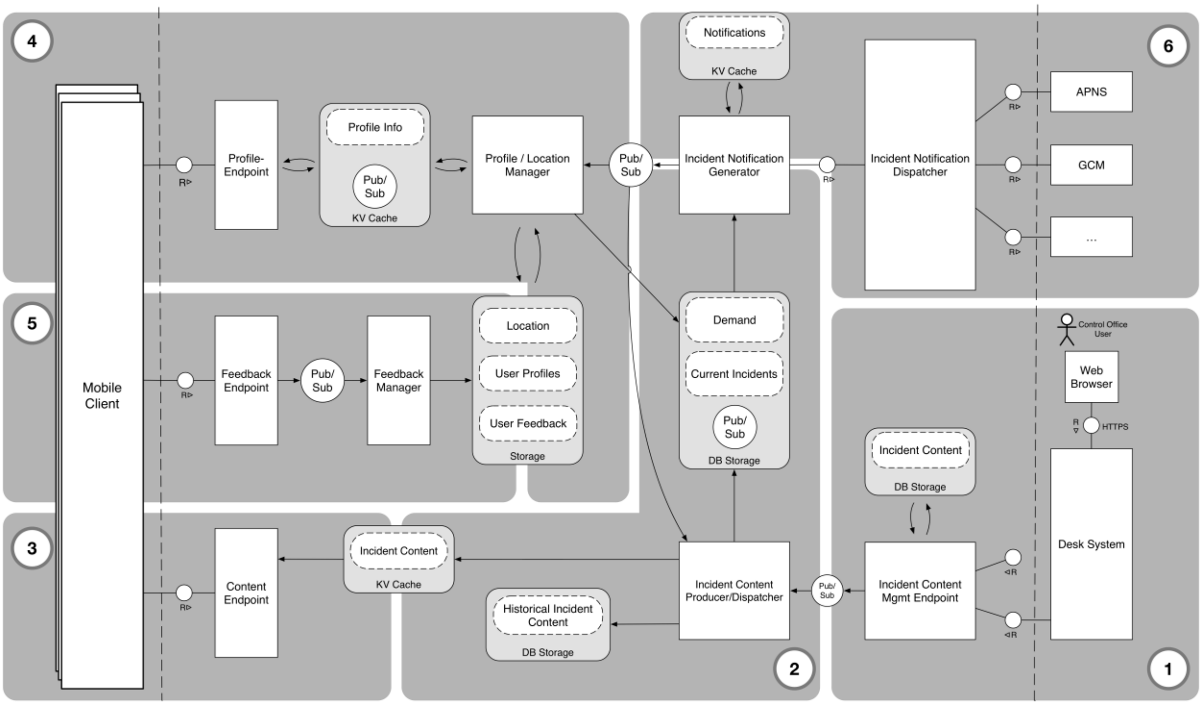

Figure 1: ENSURE General Architecture

This general architecture consists of the following major components:

1) Incident Manager: is responsible for managing incoming events (alerts or requests from the control system). It accepts event messages (raw events) via different external interfaces and saves them persistently in the *Incident Content Storage*. New or updated events are forwarded to the *Incident Content Producer/Dispatcher* and thus to the *Distribution System*.

2) Distribution System: has two main tasks a) it prepares the raw data of the incoming events and b) it is responsible for the distribution of events within the system. The processing is performed according to how the information will be further distributed. The system stores the data required for sending the notifications in the *Demand/Incident Storage* and informs the *Incident Notification Generator* about the new or updated event. It also generates the data required by the end users for the textual and graphical processing on their devices. This data is made available for retrieval via the *Incident Content Cache*. The *Incident Content Cache* serves as a buffer for content to be delivered (e.g., events such as alerts or inquiries, additional information). The *Demand/Incident Storage* maps subscriptions from system users and event messages in a high-performance runtime model that facilitates efficient matching between both types of information.

3) Content Manager: provides the interface through which to query content. This includes queries of processed events and relevant additional information. The data is taken from the *Incident Content Cache*. The *Content Manager* is designed for maximum scalability and employs dynamic load distribution.

4) Profile/Subscription Manager: presents the interface through which the user can query, add, or modify profile information. Similar to the *Content Manager*, the *Profile/Subscription Manager* uses a dynamic load distribution in order to enable, among other things, multiple profile updates within a short period of time. The Profile Manager retrieves answers to queries from the *Profile Info Cache*, which holds frequently-requested data as well as last-changed profile information in a high-performance key-value cache. The *Location Manager* is responsible for managing all profile-related data in the system. User inquiries are forwarded to the manager if they cannot be answered directly from the *Profile Info Cache*. All data is persistently stored in the *Location/Profile/Feedback Storage*. Changes to subscriptions are also send to the *Demand/Incident Storage* and forwarded to the *Incident Notification Generator* to check if a notification is required.

5) Response Service: processes all user feedback (task accepted/rejected, feedback after completion of a task, as well as feedback regarding the basic profiling). It is received and forwarded to the *Feedback Storage*.

Furthermore, the content management system can access all feedback information over this endpoint and prepare it for the dispatchers or use it as filter parameters (profile extensions) for the volunteer search.

6) Notification service: The *Incident Notification Generator* is responsible for matching subscriptions (current position, profile of user) and events. The service has access to the *Demand/Incident Storage*, a special runtime database in which the subscription and event data have already been combined. The main task is to retrieve the device addresses of the relevant volunteers for each of the event messages and send these data to the *Incident Notification Dispatcher*. In addition, this component has a store in which the notification statuses of the individual devices/users are held. The *Incident Notification Generator* also informs other system components of which devices are expected to send queries in the near future before triggering the notification delivery. This makes it possible to prepare the system so that requested information is more readily available. The *Incident Notification Dispatcher* is responsible for sending the notifications over different channels. It receives the event messages generated by the *Incident Notification Generator* along with the corresponding device addresses and sends the notifications.

5 IMPLEMENTATION

Based on the reference architecture a pilot system was developed during the ENSURE project that is fully operational with end users for test and evaluation purposes. It was developed in an iterative approach over a time line of two years taking all functional and – in particular – non-functional requirements into account. In each iteration, new functionality is added to the system and evaluated. The operational system consists of the following main subsystems:

Backend system: Based on the reference architecture described above an implementation was performed. Figure 2 shows a simplified logical architecture of the implementation, which also leaves out non-functional aspects.

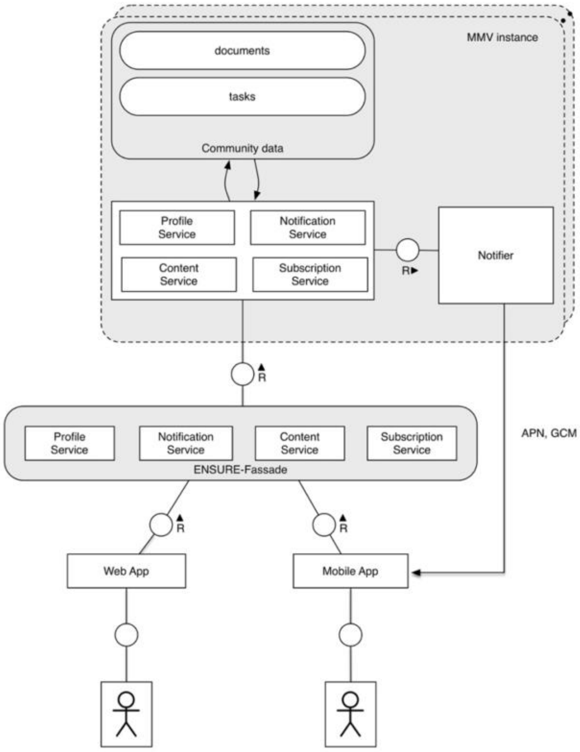

Figure 2: Logical view on the implementation architecture of ENSURE

The backend is responsible for the core processes of the ENSURE system for volunteer registration, activation, tasking and response. The system architecture was designed to ensure scalability, load balancing, performance, and availability. In order to realise the performance and scalability of the system, the following design decisions were consistently applied within the implementation:

- *Key-value caches* are used to quickly respond to queries. These are designed for the purpose of load distribution using multiple distributable instances. The number of instances can be dynamically adjusted depending on the expected or actual load. Additionally, key-value storage instances provide advantages over relational storage instances in terms of scalability.

- All data is persistently stored in databases. This means that all cache instances have persistent data storage. If an (unexpected) restart occurs, the information in the caches can be restored.
- Communication between the individual components in the system backend is asynchronous

It was implemented using server-side JavaScript technology included in the MEAN stack (MongoDB, Express.js, AngularJS, and Node.js) as well as Redis as a key value store.

Apps: The volunteer apps shown were implemented for iOS and Android devices. The apps provide the end user functionality for registration, activation, tasking and response. During registration the user can provide her/his skills that can be used for volunteer selection. For activation (Figure 3), the selected volunteers (by current location or skills) receive a message via push notification on their smartphones. The users can see all the information about the emergency operation in the app and can decide whether to accept or reject the request. After accepting the volunteer is guided through a certain task by text and/or graphics.

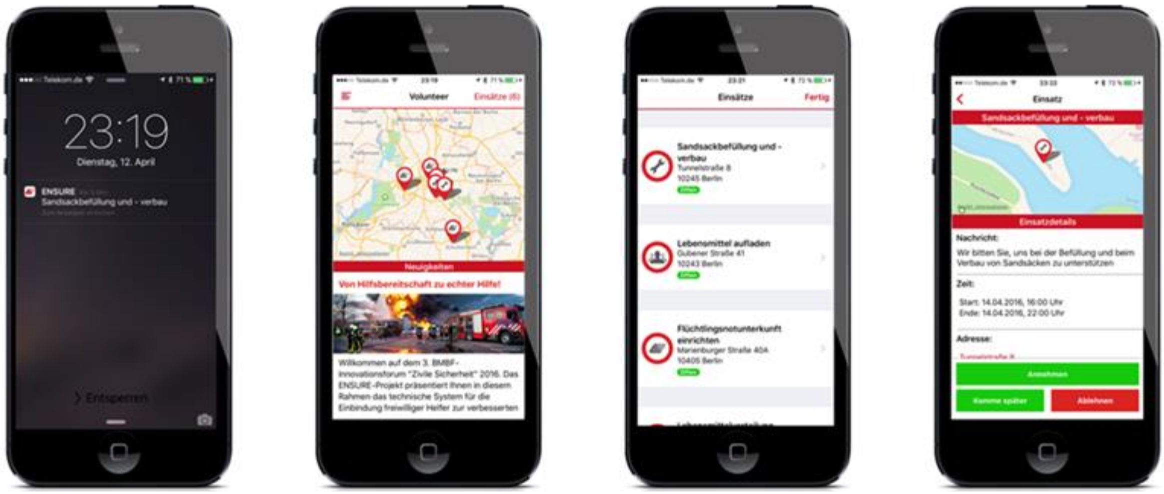

Figure 3: Volunteer activation via the mobile app

Coordination system: This web-based application is located at the emergency or disaster authorities that activate or coordinate volunteers. In this system filtering and alerting volunteers is a multistep process and proceeds as follows:

Alert type: It must first be established whether to send a regional alert or a topic-based alert.

Filtering: Volunteers are chosen based on the location and time of the emergency, the number of volunteers needed, and any special skills that may be required.

Alert details: Additional information such as specific tasks, estimated duration of the emergency operation, instructions, etc., can be added to the alert.

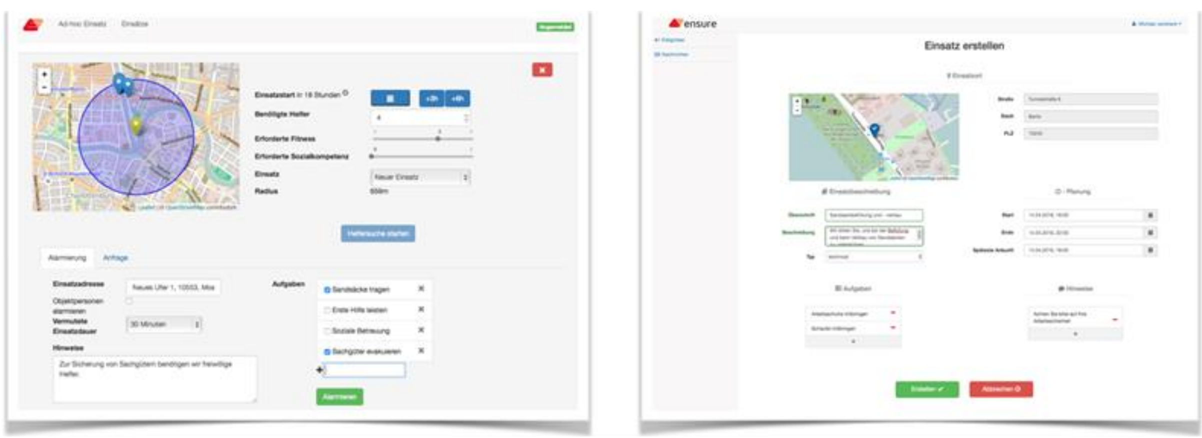

Figure 4: Volunteer activation via the coordination system

Further it provides additional functionalities such as sending updates to all users, sending additional information about an emergency operation to all users taking part in that operation, and a detailed view of ongoing emergency operations (including volunteer feedback). It was implemented as a single-page web application using the client-side JavaScript framework AngularJS.

6 TESTS AND EVALUATION

The general test and evaluation approach for ENSURE consisted of two detailed scenario-focused field exercises and one large field test in the city of Berlin. The major focus of the field exercise were to test and evaluate the system in specific response scenarios in terms of volunteer behavior and system functionality in different contexts. The exercises were preformed in October 2015 and 2016 on a special training city for police and fire brigades involving each over 140 persons (organizational staff, actors, response forces, observers, and volunteers).

The field exercise setting in an emergency training area of the city was as follows: The scenarios implicated an extreme Thunderstorm in a city with major destructions and a longer isolation phase. The 50 volunteer test persons were selected by an agency for consumer research providing of a randomly selected panel of the population by age, gender, and education. Half of them went through a special designed training for unbound volunteers. The emergency services were represented by 40 members of the fire brigades including all necessary rescue equipment. The members of the emergency services did not have a special training for on-side volunteer coordination besides a technical training on the ENSURE coordination tool. The other staff consisted of observers for monitoring the behavior and actors for the specific scenarios (persons to evacuate, injured persons, etc.). Volunteers registered for the volunteer app starting three months before the exercise. At the registration process in the app the volunteers were asked several questions in order to derive directly implicitly information about their abilities (first aid, psychological background, engineering background, languages, etc.), physical or psychological profiles. Due to privacy reasons these profiles were kept within the app and were only selected anonymously for volunteer selection. The scenarios on the field exercises consisted of the simulation of an extreme Thunderstorm in a city with major destructions and a longer isolation phase. The fire brigades selected and activated actions of volunteers by vicinity and profile through the ENSURE coordination tool both during the isolation and relief phase. Performed actions by the volunteers were beside others: evacuation of persons in buildings, securing buildings, fire distinguishing, first aid, person transport, observation for emergency services, organization of collecting places, salvation of cultural goods, helping disabled persons, or sand sack filling.

Besides the observed problems of volunteer coordination such as volunteer identification, misunderstandings between emergency services/volunteers, antagonism between integration versus collaboration, lack of specific training for collaboration on both sides, the volunteer behavior in these exercises showed a surprisingly positive result on the capabilities and effectiveness of even of untrained volunteers for certain tasks. Between both exercises a long-term field test was performed Berlin-wide open to the public in the context of supporting the fire brigades and the Red Cross for refugee aid. For the purpose the coordination system provided a selection mechanism based on time availability instead of vicinity. The profiling was reduced to a minimum since it was needed in this context. The detailed organisational, legal, sociological and psychological findings of the two field exercises and the large-scale field test are published in (Meissen and Peperhove, 2017).

In the following we focus solely on the technical aspects of the ENSURE system. This technical evaluation was performed with respect to established requirements for IT applications in disaster management in the literature (Mauthner et al., 2015) as mentioned under the non-functional requirements:

- Efficiency and safety
- Clarity and usability
- Reliability and availability

For the exercise the evaluation results were, without exception, positive in all three evaluation areas. In particular, the app was found to be very usable (SUS score: 90 points), highly stable, and had short response time as well a good success rate when storing a personal profile. First aid tasks were especially well performed (observation) and the volunteers followed instructions very accurately (clearing vehicle access routes, etc.) (see (Jendreck et al., 2016) for details).

The additional public large scale test was performed with approximately 1200 volunteers throughout Berlin from Mai until October 2016. Based on this test we have performed an additional evaluation with a major focus on response effectiveness and system performance.

Response effectiveness: Figure 5a (left) shows the overall numbers of the volunteers increasing from appr. 600 to 1200 during 2 months in Berlin without major advertisement and clear communication that this is just a test system. The lines below show the activation rate over the 8 test during this two months. It shows a relatively high acceptance at the beginning of the test (over 50%) which decreased under 40% towards the and of the test period (most likely due to the frequency of the alerts). However it shows an astoundingly high acceptance which underlines the usability of the system and the willing of the population to take part in such systems.

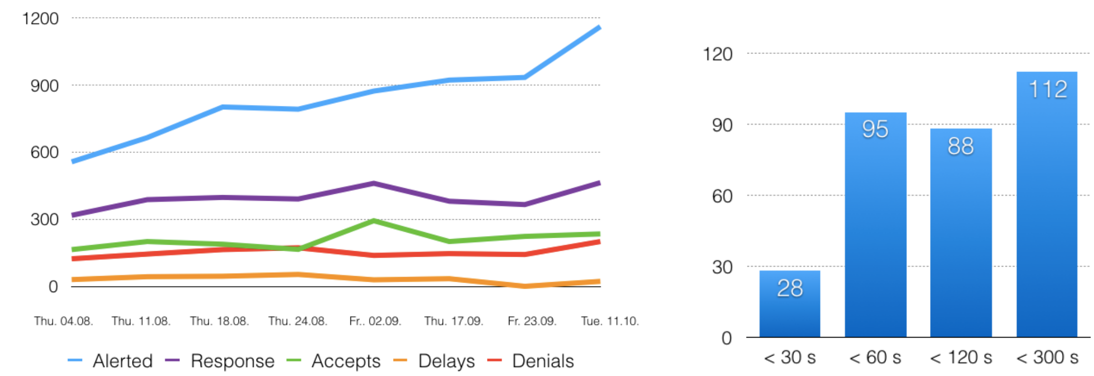

Figure 5a/b: Volunteer activation during the large scale field test

Figure 5b (right) shows the response time for the last test in October 2016 where 95% of the response was given within 5 Minutes.

System performance: Based on the fully operational system we simulated on the last test in October 2016 several performance tests by artificially increasing the number of registered volunteers to 95.000. In one test we initiated silent activations to the apps (activations received but not shown by the app) for all volunteers. Figure 6 shows that these 95.000 activations were sent out within 1 minute and 42 seconds. The testing environment consisted of 2 servers (CX40, 2VCores, 8GB Ram).

Figure 6: Activation performance for 95.000 volunteer devices

All further test results showed a high robustness of the system (no failure or downtime during 6 months of tests).

CONCLUSION AND FURTHER RESEARCH

Interactive, collaborative, and mobile technologies have the potential to overcome the challenges involved in the integration of volunteers into crisis and disaster control. The goal of the ENSURE system presented in this paper is to support the aid forces in recruiting, managing, activating, and coordinating volunteers in an urban area in the event of a large-scale emergency. To achieve this, ENSURE provides necessary functions such as volunteer registration, volunteer profiles, sending alerts (from the control system), and volunteer activation (via the mobile app). The system uses a subscription-based approach in which the volunteers agree to take part in an emergency operation by responding to an alert. The reference architecture provides technical insights into how to implement the combination of alert and crowdtasking systems. The implementation of the reference architecture proved its feasibility during two field exercises and a public large-scale field test, and showed the general applicability of the approach in terms of end user behavior, functionality and non-functional aspects. Given all open issues in the organizational, legal and sociological aspects in the practical use of such volunteer systems that differ from application scenarios, countries, organisations and target groups the system should be highly flexible, which is guaranteed by the highly modularized architecture of the presented system. This is also necessary in order to provide a support a variety of application scenarios over all categories presented in Section

3 as shown in the scenarios of the field exercises/tests in order to provide the psychologically necessary activation frequency for volunteer motivation in one system.

With the expected application of such systems it will be of high interest how volunteers behave in real crisis scenarios but also in standard emergency scenarios. The system architecture offers a variety of measure points that in sum provide a promising anonymous data collection basis for future research in that direction.

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Prevention and Preparation

Social Triangulation: A new method to identify local citizens using social media and their local information curation behaviors

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ABSTRACT

Local citizens can use social media such as Twitter to share and receive critical information before, during, and after emergencies. However, standard methods of identifying local citizens on Twitter discover only a small proportion of local users in a geographic area. To better identify local citizens and their social media sources for local information, we explore the information infrastructure of a local community that is constituted prior to emergencies through the everyday social network curation of local citizens. We hypothesize that investigating social network ties among local organizations and their followers may be key to identifying local citizens and understanding their local information seeking behaviors. We describe Social Triangulation as a method to identify local citizens vis-à-vis the local organizations they follow on Twitter, and evaluate our hypothesis by analyzing users' profile location information. Lastly, we discuss how Social Triangulation might support community preparedness by informing emergency communications planning.

INTRODUCTION

Local citizens represent an important source and target for information during emergency situations. These citizens are located in a geographic vicinity and many are social media users, however, matching social media users to a particular geographic vicinity poses a challenge of discovery for researchers as well as local citizens and officials. As Landwehr and Carley (2014) write:

> Locals at the site of the disaster who are posting information about what they are witnessing are in many ways the gold of the social media world, providing new, actionable information to their followers. They are few in number, and while their messages are sometimes reposted they often don't circulate broadly. Locating their content is an ongoing challenge akin to finding a needle in a haystack. (p. 2)

Local citizens using social media platforms such as Twitter have been previously identified through content analyses that attempt to triangulate a user's location using geographic references included in a tweet (Olteanu, Vieweg and Castillo, 2015; Starbird and Palen, 2012), or through direct location information such as geotags (de Albuquerque, Herfort, Brenning and Zipf, 2015; Kogan, Palen and Anderson, 2015). While content analyses necessarily locate users post hoc, depend on unique location references, and encounter difficulties at scale, geotags are affixed to only 1.5-3.2% of all tweets (Morstatter, Pfeffer, Liu and Carley, 2013). Users who include location information in their profile present an alternative, however, some users do not disclose their location, or decide to include ambiguous or non-geographic information instead (Wang, Harper and Hecht, 2014, p. 74).

These methods of identifying local citizens set important conditions for localness: the users are necessarily active citizens posting tweets often in the midst of emergency and using keywords or hashtags that come to be queried by those interested in accessing locally generated information (Grace and Leskovich, 2015; Starbird and Palen, 2010). In this respect important methods for keyword-based tweet collection and subsequent location-based sub-sampling have been advanced (Olteanu, Castillo, Diaz and Vieweg, 2014). However, the successive subsets of users who actively post messages, include queried keywords, as well as location data of some kind, stand to leave a significant population of local citizens who use social media to *receive* information *before* an emergency invisible to others in the information space, as well as public officials seeking to provide warning notices or gain timely on-the-ground information.

Instead, we explore the utility of a novel method of Social Triangulation (ST) to identify local citizens as recipients of local information who can be identified before emergencies occur. ST is motivated by the basic assumption that people using social media and living in a geographic area curate their social networks to include local organizations both physically present in their geographic area and disseminating social media intended for that area. In the case of Twitter, the assumption suggests local people follow local organizations. Similar to methods of community asset mapping performed by urban planners (Kerka, 2003; McKnight and Kretzmann, 1997), ST involves first cataloguing a comprehensive list of local organizations maintaining Twitter accounts- local media, citizens' associations, businesses, civic and emergency services, etc., in order to discover users curating their social networks to receive information from these organizations, and thus the opportunity to identify these users as local citizens. Moreover, by understanding patterns of social network curation among local citizens, that is, where and in what variety they receive local information through social media, we can understand the *information infrastructure* of a local community.

In this paper, we first describe the method of ST and then evaluate the validity of its basic assumption. We do this through an exploratory application of ST to a small city in the Northeastern United States. We catalogue and categorize 195 community assets in this community, identify their collective 185,176 Twitter followers, and then, using available profile location information, evaluate the extent to which these followers are indeed "local." We find promising evidence supporting our basic assumption: among 79,998 users for whom we have location information, we find that fully 68% identify themselves as local citizens. Moreover, the more local organizations a user follows the more likely they are to identify as local citizens: For followers of only one organization, 67% identify as local citizens, while 71% of those following 3-9, 84% of those following 10-49, and 98% of those following 50 or more organizations, respectively, identify as locals. We discuss further efforts to validate our assumption and future work using ST as a localization method in our discussion.

Additionally, we explore the information infrastructure of the community to understand from what information sources, and in what variety, local citizens receive local information on Twitter. Our exploratory study points to *differences in the level and position in which citizens are embedded in the information infrastructure of a community.* Specifically, we find that a majority of loosely embedded citizens tend to curate and receive information from only local media sources, while a deeply embedded minority is positioned to receive more and various kinds of community information relative to the latter, especially information disseminated by citizens' associations as well as civic and emergency services.

We therefore find utility in ST as a method supporting community preparedness, capacity, and resilience-building. By systematically cataloguing and mapping community assets that act as important sources of local information on social media, as well as the people who receive information from them (and those who don't), ST can inform emergency communication planning by pointing to groups of local citizens not directly receiving emergency or risk-related information, as well as the local social media accounts that reach these segments of the community. Drawn from our particular community study, we offer general recommendations for local emergency communications strategies.

This paper is organized as follows: first, we review work in crisis informatics literature to point out that local citizens, as information recipients, tend to be excluded by current collection and localization methods. Second, we present the procedure of ST by deploying it to explore the information infrastructure of a small city in the Northeastern US. We then describe our findings related to local information curation behaviors we observe, as well the evaluation of the localness assumption behind ST. Lastly, we describe the merits of ST as a community preparedness tool and opportunities for future work.

WHY IS IDENTIFING LOCAL CITIZENS IMPORTANT?

Local citizens consist of people living together in a geographic region. Local citizens constitute communities, and are thus the primary producers and recipients of community information. In crisis informatics research, local citizens represent those closest to and most affected by natural and man-made disasters, as well as more common emergencies, and take part in emergency situations as eyewitnesses and citizen responders. As a result, local citizens produce actionable, and situational information to other locals, emergency response and relief officials, as well as a global crowd of interested observers, journalists, and digital volunteers (Starbird, Muzny and Palen, 2012; Starbird, Palen, Hughes and Vieweg, 2010). Moreover, local citizens live and work in towns, cities, and regions where they intimately know and shape the geographic, cultural and built infrastructure, and thus stand to provide unique and critical information during times of emergency (Starbird, Muzny and Palen, 2012).

As information producers, local citizens provide "generative information," primary accounts and interpretations of emergency-related events that Starbird and Palen (2010) take as the "the core of the information production cycle" (p. 246). Studies identify local citizens as individuals who are more likely post messages related to emergencies in their vicinity than social media users geographically-removed from events (de Albuquerque et al., 2015; Lachlan et al., 2014). Moreover, suggesting the importance of social networks for disseminating information, studies observe that local citizens are more likely retweet generative information created by other local citizens than the globally-distributed crowd (Kogan et al., 2015; Starbird and Palen, 2010). Whereas local citizens more often provide information about affected people and actionable information useful to other local citizens, the globally distributed crowd of social media users most often post messages of sympathy and support for those affected by a crisis (Olteanu et al., 2015). However, the distributed crowd of users- by retweet- can amplify and direct attention to local citizens' messages, or disseminate relevant URLs to other information sources online (Starbird and Palen, 2010; 2012).

As information recipients, local citizens represent the people to whom government and relief organizations attempt to communicate situational updates and directives during emergency situations. Studies find government and emergency response organizations adopt social media in emergency situations (Graham, Avery and Park, 2015; Hughes and Palen, 2009), and use social media to disseminate emergency warnings to local citizens before emergencies (Rice and Spence, 2016; Veil, Buehner and Palenchar, 2011). During and after emergencies, governments and NGOs post social media to convey important information to affected locals on the progress of relief operations, and the location and availability of emergency assistance (Olteanu, Vieweg and Castillo, 2015; Tim, Pan, Ractham and Kaewkitipong, 2016). In non-emergency contexts, municipal governments and public services, such as police departments, seek to communicate crime and traffic updates to the public, and also solicit information about missing persons and wanted suspects (Huang et al., 2016).

However, in the globally-expansive information space of social media, identifiable local citizens remain rarities (Starbird et al., 2010). Analyzing across many crises events, Olteanu et al. (2015) find local citizens' social media to typically account for an average of 9% of crisis-related messages on Twitter. In non-emergency contexts, social media might substantially lessen in volume, but lack the contextual data features- hashtags or crisis-related keywords- that assemble and make local information commonly accessible (Bruns and Liang, 2012). Yet while identifying local citizens within the voluminous and complexly-assembled information space of social media remains "akin to finding a needle in a haystack," their critical roles as information producers and information recipients require effective methods of localization to inform community information sharing in both emergency and non-emergency settings.

HOW HAVE LOCAL CITIZENS PREVIOUSLY BEEN IDENTIFIED?

Typical methods in crisis informatics collect Twitter data vis-à-vis the words people include in the content of their messages or, alternatively, geolocation information people append to tweets or descriptive locations entered in user profiles. These methods typically involve engaging Twitter's public API and can be referred to as keyword or location-based collection respectively (Olteanu, Castillo, Diaz and Vieweg, 2014, p. 376). Importantly, these collection methods set important conditions for identifying local citizens.

Location-based Collection and Localization

Local citizens can be identified on the basis of geographic coordinates (i.e. geotag) associated with a particular tweet, or location information included in a user's profile. Using Twitter's public API, queries can be constructed to retrieve tweets containing particular words or hashtags, or tweets with a location-identifier corresponding to a geographic area or bounding box specified by a set of geographic coordinates. Due to issues of relevance and comprehensiveness involved with using Twitter's REST and Streaming API, keyword-based data collection often precede location-based subsampling and subsequent identification of locals (Kogan et al., 2015).

For instance, to identify geographically vulnerable Twitter users during Hurricane Sandy, Kogan et al. (2015)

first selected eight “carefully chosen” keywords to collect tweets through Twitter’s Streaming API. Among the users whose tweets were collected, users posting at least one geotagged tweet within a boundary box encompassing part of the United States Eastern Seaboard were selected as the basis for a subsequent round of data collection involving the REST API, by which the authors could collect up to 3200 of these users’ most recent tweets (p. 983). This approach to identifying locals thus involves two important filters: those who use a specified set of keywords in their tweets and, the small minority among those users who also posted a geotagged tweet in the affected locale.

Using geotags to identify local citizens remains limited by the paucity of users who include geographic coordinates in their tweets- as a result only 1-3% of tweets carry geotags (Morstatter, Pfeffer, Liu and Carley, 2013). Consequently, local citizens posting geotagged tweets represent only a fraction of those actively posting content on Twitter in a geographic location, and none of the people who might use Twitter but do not actively tweet, or at least did not do so during the period of data collection. Among the latter, a PEW Research Center (2015) study found that 28% of Twitter users did not tweet during a one month period, and an additional 33% posted fewer than nine messages. Among those who did tweet, 30% of all tweets were retweets (for news-related tweets this rose to 49%) - a notable figure when considering that location-based queries to the Streaming API do not retrieve retweets (Twitter, 2016).

Content and Keyword-based Collection and Localization

Alternatively, content and keyword-based methods revolve around the relationship between the lexical scope and distribution of words curated by both locals and a global crowd using Twitter to discuss a crisis, and the selection of specific keywords held to represent and, in effect, constitute the crisis information space. The users whose tweets contain these keywords and hashtags can subsequently be identified as local citizens by using tweet geotags or profile location information, as described above, or coding methods to determine a user’s location on the basis of the content of the tweets they post, for instance, if it is judged to be an “eyewitness” account (Olteanu et al., 2015).

Using the Streaming API to examine the 2011 Egyptian political protests, for example, Starbird and Palen (2012) relied on Arabic speakers in their research lab to select certain keywords “as the most popular during the early days of this event” (p. 9). Thus if a local protester, even if at the center of Tahrir Square, did not include one of the keywords “egypt,” “#egypt,” or “#jan25,” they would never be identified by the authors and, more significantly, perhaps other locals and the global crowd. Starbird and Palen (2012) coded the retweets of active users on the basis of “assertions of or references to being in Cairo during the period of the protests.” Accordingly, users were assessed as either in Cairo, in Egypt but not in Cairo, or outside Egypt. The authors thus identified local citizens as any Twitter user posting a tweet including at least one of the three queried keywords, and judged as being in Cairo at least once within the defined collection period (p. 10).

Keyword-based methods necessarily focus on highly-visible terms that ignore tweets missing the particular keywords queried and the users who post them or do not tweet at all (Bruns and Liang, 2012; Olteanu et al., 2014; Vieweg et al. 2010). Keyword curation can amplify the non-local, as it “assume[s] to establish a dataset of the most visible tweets relating to the event in question, since it is the purpose of topical hashtags to aid the visibility and discoverability of Twitter messages” (Bruns et al., 2012). While keywords and hashtags stand to benefit those affected in the vicinity of a crisis, the emphasis on visibility and discoverability especially aids the geographically-removed crowd who generally lack existing social network connections to local people and organizations.

Moreover, Vieweg et al. (2010) suggest that familiarity with a locale, such as possessed by local citizens, can lead user’s to omit the very keywords or hashtags that would identify them to others as local. What they describe as “markedness” refers to:

> how certain places, landmarks or items become taken-for-granted and expected when referred to in more general terms. The RR data set was collected based on search terms “red river” and “redriver”, and within this data set, if someone mentioned “the river” or “the flood level” it was commonly understood to be about the Red River, which makes the Red River “unmarked”— no detail is necessary when referring to it. (p. 1086)

Thus if someone only provided information on “flood level” such data would only become visible to the authors if, in another tweet, they had also mentioned one of the two keywords or hashtags queried for data collection. In the course of their retrospective examinations of three distinct crises events, a school shooting, tornado, and flood, Saleem, Xu and Ruths (2014) find that initial tweets concerning these events often fail to include references to places or the type of emergency, as well as visible hashtags associated with the event. The authors conclude that “the first tweets carrying situational information tended to lack the kind of identifying keywords and hashtags that would make them easy to discover in a full Twitter stream" (p. 156).

Together location and content/keyword-based methods set important conditions for localness. These methods risk omitting the 97-99% of users without geotags, those tweeting without identifiable keywords, or those who do not actively tweet but rely on social media for local information. As an alternative, we now introduce ST in order to i) identify local citizens in non-emergency contexts, ii) identify a greater proportion of local citizens than standard methods, and c) identify local citizens without relying on geotag and profile location data, or data from tweet content.

METHOD

We deploy ST by cataloguing community assets located in a small city in the Northeastern US, and analyze the information curation behaviors of local citizens who curate the Twitter accounts of these community assets within their social networks. Information curation "involves future oriented activities," consisting of a "set of practices that select, maintain, and manage information in ways that are intended to promote future consumption of that information" (Whittaker, 2011, p. 7). Here, curation involves practices of "following" community assets, specifically local organizations, by Twitter users who, as a result, enable ongoing access to local information disseminated by these organizations. Shared patterns of curation among people following local organizations reveals the information infrastructure of the local community, and reveals which groups of local citizens curate their social networks to directly access types of local information, as well as those who do not.

Our exploratory analysis of ST is guided by three questions:

1. How many local organizations do people typically curate within their social networks?
2. What patterns of information curation exist among people following local organizations?
3. What is the relationship between information curation behavior and a person's geographic location?

We describe the information gained using ST by characterizing descriptives of user curation behavior, comparing Twitter users identified using ST to the location mentioned in their profile, and finally, we describe the types of local organizations that socially triangulated Twitter users co-follow to better understand the information infrastructure of the local community.

Our methodology involves a four phase process of social triangulation (ST) to locate Twitter users in a geographic area: (1) categorizing of community assets, (2) cataloguing community assets, (3) collecting user information, and (4) analyzing geographic characteristics and information curation patterns.[1] To socially triangulate Twitter users, we began by identifying categories of public and private organizations to organize our search for community assets in one city in the Northeastern Unites States. Urban planners often assess community capacity and resources using community asset mapping methods which search for organizations in a community by type (Kerka, 2003; McKnight and Kretzmann, 1997). Similarly, we identified types or categories of organizations- public institutions, citizens' associations, local economy (e.g. businesses), and media- which we subsequently modified and expanded by searching for and cataloguing organizations maintaining a Twitter account in the city of interest. The resulting eight categories of community assets are listed in Table 1.

The initial categories functioned primarily to organize our search for local organizations. This involved a grounded process in which online directories and search engines were used to explore the diversity of local organizations in a particular community asset category and determine which types of organizations in that category maintain an identifiable social media presence. For example, beginning with the community asset category of local economy we used community directories (e.g. yellow pages) and general online searches (e.g. restaurants in...) to categorize and identify types of businesses maintaining Twitter accounts. We subsequently identified three categories- restaurants, bars, and entertainment. Importantly, the categories reflect local economic assets with a social media presence and not a comprehensive catalogue of community businesses. For example, beginning within the community asset category of citizens' associations, we initially speculated that the numerous churches and worship centers in the city might have a significant social media presence, however, upon investigation, we subsequently discovered that very few were on Twitter.

[1] ST represents a form of geolocation inference, techniques using social network relationships to infer a user's location (Backstrom, Sun, and Marlow, 2010; Jurgens, Finethy, McCorriston, Xu, and Ruths, 2015). However, ST differs by focusing on the process of establishing a single "ground truth" location by cataloguing important information sources located in a geographic area, and in relation to which all users' locations are inferred. For Twitter most geolocation inference methods use geotags or profile location information for ascertaining ground truth, and thus encounter similar constraints of other localization methods (Jurgens et al., 2015).

Table 1. Categories of Community Assets

Category	Description	Number
Citizens' Associations	Volunteer, social, and nonprofit organizations, e.g. habitat for humanity, environmental conservation groups, historical society	41
Civic Services	Civic government and public services, e.g. municipal government, public library, public transit	18
Emergency Services	Emergency management and response services, e.g. police and fire departments, EMS, university emergency alerts	13
Schools	Municipal school district, e.g. elementary, middle, and high schools, local vocational school	16
Bars	Establishments of good cheer, e.g. bars, saloons, taverns, wineries, and pubs	27
Entertainment	Recreational businesses, e.g. minor league baseball team, golf courses, movie theaters	5
Restaurants	Local (non- chain) food-serving establishments, e.g. cafes, diners, delis, pizzerias	43
Media	Local media, e.g. newspapers, newsletters, news websites, radio, television	32
Total		195

The second stage of ST involved developing a comprehensive catalogue of organizations for each category. The grounded process of identifying local organizations and arranging them into categories described above yielded an extensive catalogue of organizations, however, we sought to develop, to the best extent possible, a listing of all identifiable organizations both located in the local city and maintaining a Twitter account for each category selected. Additionally, we created a project Twitter account to utilize Twitter recommendation algorithms to suggest additional organizations and searched among the followers of these organizations, as well as the accounts each organization follows, to identify any organizations that did not appear through our online searches.

Third, using Twitter's REST API we collected the Twitter IDs of accounts following each local organization. For example, among the public services in the city we catalogued the city's bus system and collected the account IDs for the 1,011 people that follow the official bus system account on Twitter. In total, we collected 185,176 Twitter IDs, each following at least one of the 195 local organizations catalogued. The follower counts for each organization reflect the period of our data collection, which occurred during the week of December 5, 2016.

The fourth phase of ST involves evaluating the localization assumption behind ST, and analyzing the kinds and variety of local information users access through their social networks. For the latter we analyze 1) the curation patterns among those following local organizations and 2) the relationships among organizations with respect to users' curations patterns. The two analytical methods are further described below.

Geographic Analysis

We utilized profile location self-identified among the 185,176 Twitter users in order to understand their location relative to the number of organizations they follow. Using a Java program written to search the Twitter API, we found Twitter accounts available for 168,452 of these accounts. Of these, 79,980 accounts included profile information.

By importing this information into Google Fusion Tables we geocoded each of the self-described locations by relying on similar tools that are used to identify non-uniform information in Google Map search. Errors in geocoding can occur due to misspellings in the location, and ambiguous locations which match multiple, similarly named places in the world. During Google's geocoding process, between 12 – 15% of the locations were reported as ambiguous, and unavailable for geocoding. The identifiable locations were plotted on a Google Map to better understand the locations self-identified by Twitter users with respect to the number of local organizations they follow.

Social Network Analysis

Using the data collected, we constructed a 2-mode matrix where one mode was comprised of the Twitter accounts of each of the 195 local organizations and the second mode was comprised of the 185,176 Twitter users that followed those organizations. With an interest in uncovering patterns in curation behaviors among various data streams, we created a weighted 1-mode affiliation matrix that represents Twitter user co-followership of the 195 local organizations. In this network, each node is a local organization and each link among organizations is weighted by the number of Twitter users that co-follow both organizations.

Organizational categories were used as node attribute information in order to describe the relationships among types of local communities. Further, we developed a method to examine an attribute-based model of structuration of the local network. This was performed by first creating a table of homophily scores using a standard E-I index. Here, each "same category" tie is treated as an internal group tie and every "different category" tie is treated as an external group tie, in which the number of ties external to the groups (E) minus the number of ties that are internal to the group (I) are divided by the total number of ties in the network (Krackhardt and Stern, 1988). The homophily scores table was then treated as a 2-mode matrix to create a 1-mode affiliation matrix representing inter-category ties among various types of Twitter information streams resulting in a community asset network.

RESULTS

The following section describes the results of the descriptive and comparative analysis of Twitter followers identified using ST. We begin with a descriptive account of information gathered using our method and follow with analysis to better understand information curation behaviors among Twitter followers of the local organizations we catalogued.

Descriptive Analysis of ST

ST identifies people who curate local organizations within their social networks, and thereby become recipients of local information and embedded in the local information infrastructure. Among users curating at least one of the 195 citizen's associations, public institutions, businesses, and media organizations in their social networks, how many and what categories of organizations do they follow? Figure 1 displays the following distribution of the 185,176 users, indicating different *levels* of embeddedness within the local information infrastructure. On average each user follows 1.82 organizations, with 75.3% (139,440) of all user following only one of the 195 organizations we catalogued in the city.

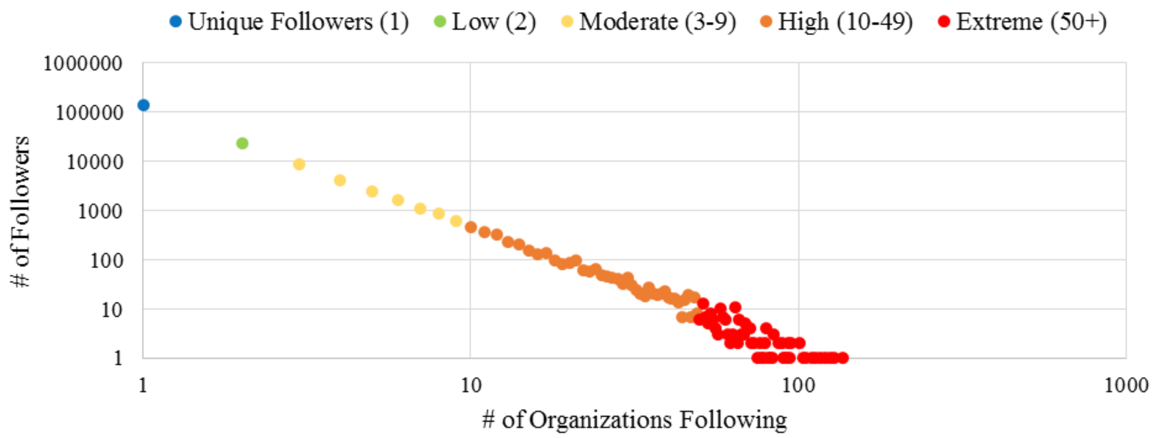


Figure 1. Distribution of users relative to the number of local organizations they follow (colored by levels of local information following).

Dividing the 185,176 users according to how many organizations they follow reveals five types of local information followers and information recipients we categorize as: unique, low, moderate, high, or extreme. As described, the majority of all users follow only one local organization and thus we consider them as unique recipients of local information. Low followers, 12.4% (23,027) of all users, follow only two organizations.

Medium, 10.5% (19,397), and high followers, 1.7% (3,147), follow between 3-9 and 10-49 organizations respectively. Accounting for only 0.1% or 165 of all users, extreme followers curate 50+ organizations within their social network, such as one user who follows a total of 139 local organizations. This following distribution indicates, on one hand, a highly embedded minority of users (medium-extreme followers) receiving multiple information streams within the community and, on the other, a weakly embedded majority (unique-low followers) that directly receive information from only one or two organizations.

Looking to the categories of organizations users follow points to important differences in what kind of organizations people choose to curate within their social networks, receive information from, and thereby different positions of embeddedness within the local information infrastructure (Figure 2). Comparing unique followers to high and extreme followers, for instance, reveals a stark contrast in their curation of media organizations (see Figure 2). Among the 139,440 people who only follow one local organization, over 106,000- 58% of all users- follow one of 32 local media organizations. In contrast, medium, high, and extreme followers curate multiple and more diverse organizations within their social networks. Among high and extreme followers, citizens' associations and public services account for approximately 40% and 50%, respectively, of the organizations curated within their social networks. These distributions indicate that local citizens are differently positioned within the local information infrastructure, that is, different segments of the community receive information from different sets of local sources. Thus a minority of highly embedded users follow more organizations and receive a different variety of local information from a balance of media and business organizations, and civic offices and volunteer groups. On the other hand, a majority of weakly embedded users follow few organizations and of less variety, with most receiving information only from local newspapers, radio stations, or telelvision sources.

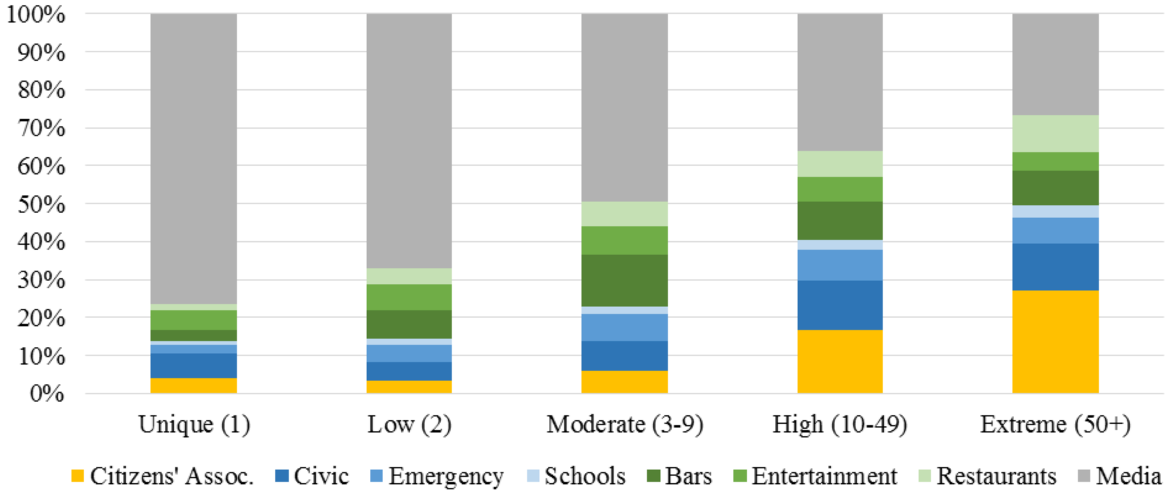


Figure 2. Proportion of Community Assets Followed by Each Type of Local Information Recipient.

Evaluation of Followers' Location

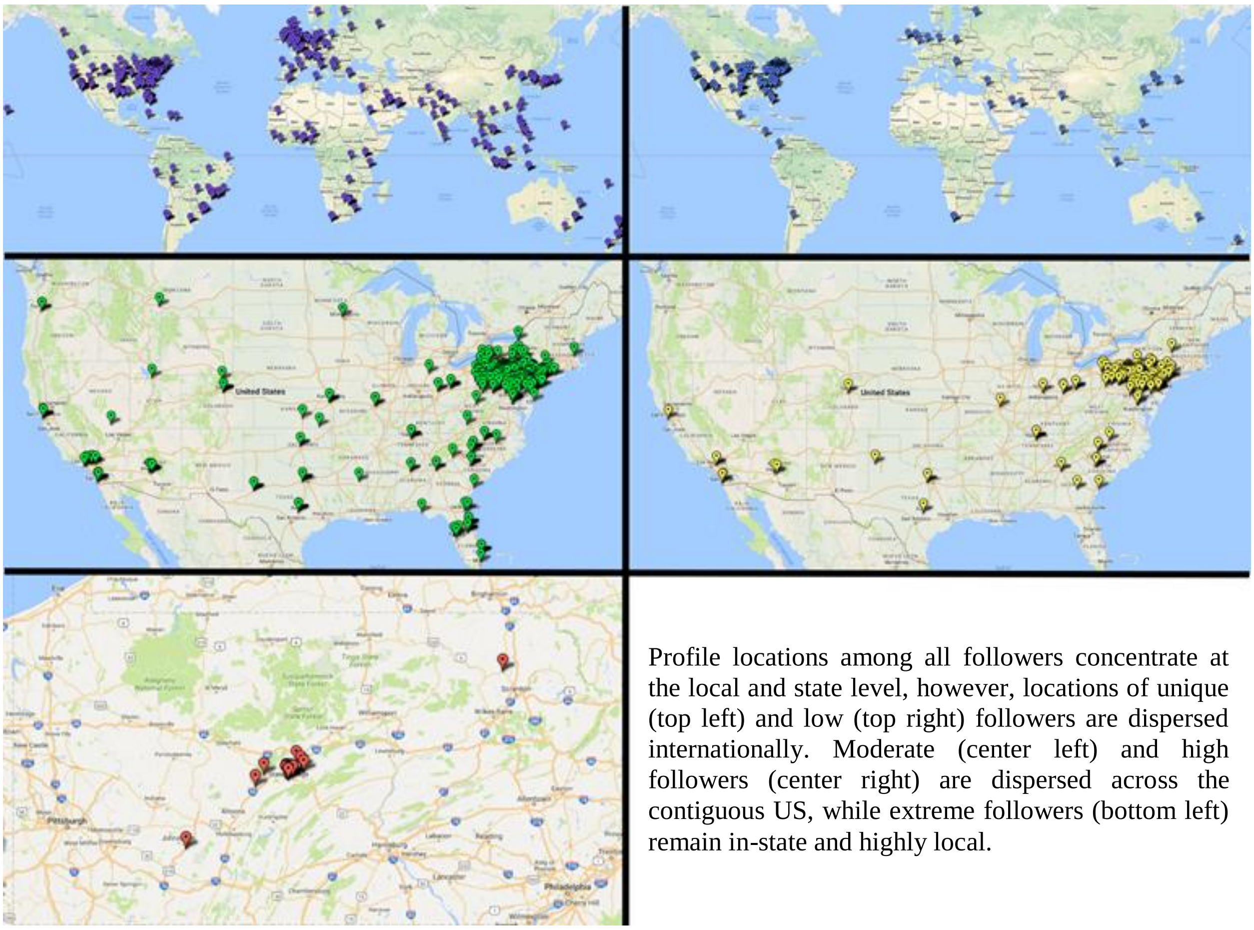
Next, we evaluate the location information of people who follow local organizations in order to understand the relationship between information curation behavior and a user's location. That local citizens will tend to follow and receive information from organizations in the geographic area in which they live motivates ST as a method for identifying local citizens. In order evaluate this assumption we use the location information users include in their Twitter profile to better understand the location of people following local organizations and how this might vary according to the number of organizations they follow (Table 2). Of the 185,176 users following a local organization, 43% include an identifiable location in their profile. Among those with location information, 91% are local to the state, and 68% identify their location within the municipality. Altogether, we find that 72,638 followers, or 29% of all users following a local organization, are local citizens of the city.

Differences, however, appear among followers at different levels of embeddedness within the local information infrastructure. That is, depending on how many local organizations a user follows, we observe differences in the availability of location information and the proportion of followers who identify as living in the local community. First, among unique followers we find only 41% to have included an identifiable location on their Twitter profile. In comparison, 68% of high followers and fully 88% of all extreme followers included profile locations. Significantly, in the locations identified among these users, we find that nearly all followers who include location information on their profile are located in state (91%), and 68% identify as local to the municipality itself. Moreover, among high and extreme followers who include profile locations, 84% and 98%, respectively, identify as local citizens.

Table 2. Evaluation of Follower Geographic Locations

Orgs. Following	Total Users	Users Located	%	In State	%	In City (25km)	%
Extreme (50+)	165	146	88%	146	100%	143	98%
High (10-49)	3147	2142	68%	2058	96%	1809	84%
Moderate (3-9)	19397	10404	54%	9755	94%	7361	71%
Low (2)	23027	10530	46%	9796	93%	7064	67%
Unique (1)	139440	56756	41%	50883	90%	37788	67%
Total	185176	79978	43%	72638	91%	54165	68%
Among all users				72638	39%	54165	29%

Lastly, we mapped the profile location information included by users using Google Fusion Tables and Google Maps (Figure 3). Separately mapping the self-identified locations of users at different levels of embeddedness in the local information infrastructure, dramatic differences in the geographic dispersion of users' locations become revealed. Among unique and low followers, users identify locations spanning around the globe. For instance, a follower of a local bar indicates in his profile that he is from Iraq, while a baseball-related twitter account in Cuba follows the local minor league baseball team.



Profile locations among all followers concentrate at the local and state level, however, locations of unique (top left) and low (top right) followers are dispersed internationally. Moderate (center left) and high followers (center right) are dispersed across the contiguous US, while extreme followers (bottom left) remain in-state and highly local.

Figure 3. Geographic dispersion of followers identified by ST

In contrast, the user locations of moderate and high followers are less dispersed and remain concentrated at the state and regional level, although many locations are indicated throughout the United States. Among extreme followers, all identify their location within the local municipality except two whose location remains in-state and within 200km. While the presence of a major public university with a large international student population likely accounts for many of the internationally-dispersed user locations, the locations of users outside the municipality become less dispersed and more regionally concentrated among those who follow multiple local organizations.

Description of Local Information Curation Behaviors

Figure 4 displays the co-following network structure of the 195 local organizations who share a link if they are followed by the same Twitter user. The network is very dense, wherein 96.6% of all possible ties are present, and has a low overall degree centralization at only 3% of the network being centralized around a few nodes. This network is very tightly bound with a network diameter of two and the average distance between any two nodes is 1.034. While many whole network measures of the network are not very descriptive of distinguishable measures in the network, a weighted measure of centrality shows that the whole network homophily E-I index among organizations links by same organizational type is 0.6892. In an exploration of the one-mode representation of the local information infrastructure divided by local information recipient types found similarly high densities with low diameter. This indicates that by the methods used in this analysis, this community appears to have very little fragmentation in its information infrastructure.

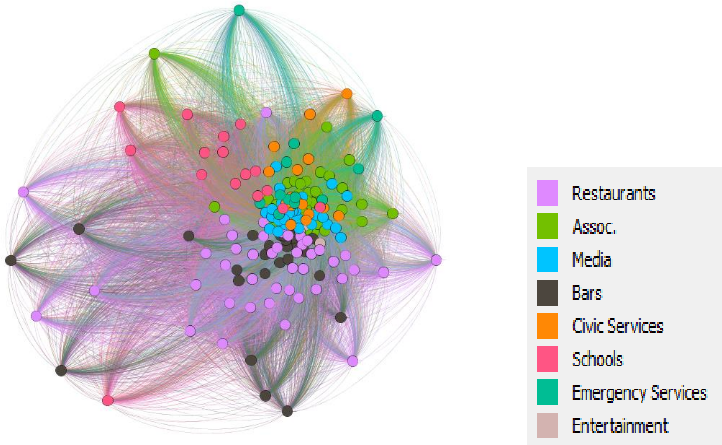


Figure 4. Sociogram of 1-mode affiliation matrix of local organizations (colored by organizational categories).

The next phase of this work was to utilize homophily scores for individual categories to develop an attribute-based model of structuration weighted by overlapping same category ties, which is displayed in Figure 5. As seen below, Civic Services (such as the local police department and bus) is the organization type with the most followers. Civic Services weakest links are to entertainment, followed by the media. Citizens' Associations is the organization type with most overlap in followership with other organizational types, in some ways placing it at the center of the information infrastructure of the community. Although Citizens' Associations display strong ties to most categories, its weakest link was to Entertainment, followed by Media. Comparatively, the Entertainment category had relatively weak ties to most categories. In a comparative analysis among the types of local information recipients, Twitter users in the extreme and high categories produce a similar information infrastructure, whole those in low and moderate categories produce an information infrastructure that displays strong ties among citizens associations and all other categories, as well as moderately strong tie among bars and emergency services. By virtue of this methodology, individuals in the unique category do not produce links among organizational types.

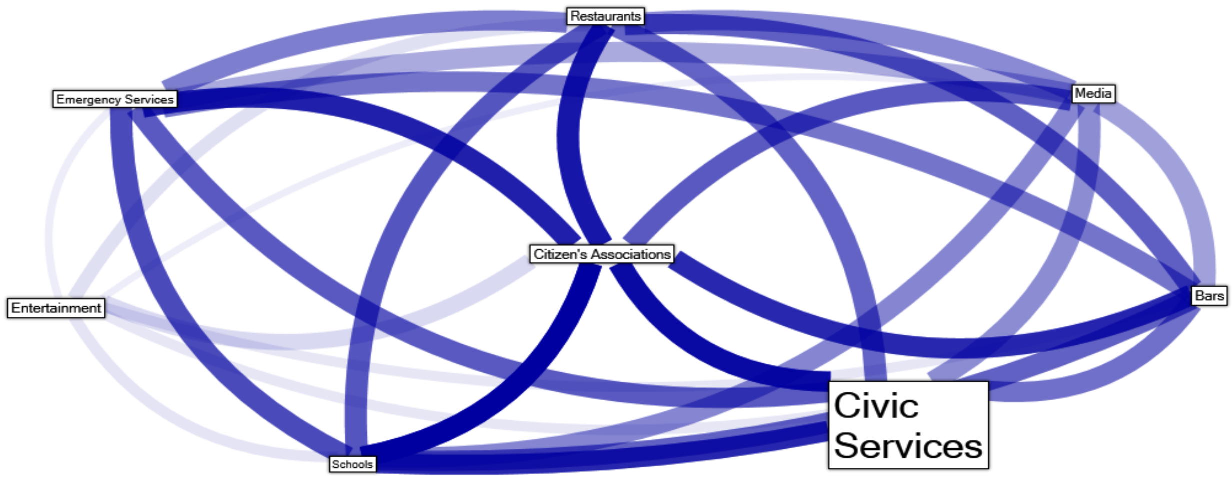


Figure 5. Attribute-based Model of Structuration of Community Assets (Labels sized by number of followers; ties weighted by co-followership).

DISCUSSION AND CONCLUSION

In the exploratory study we present, we find evidence to support the underlying assumption of ST: that local citizens tend to curate their social networks around organizations in their geographic area. Among the 79,998 users following a local organization in the particular city situating our study, and for whom we have location information, we find that fully 68% identify themselves as local citizens. Moreover, the more local organizations a user follows the more likely they are to identify as local citizens. For followers who have curated only one or two local organization in their social network, 44,885 or 67% identify as local citizens. This increases for those who follow 3-9 organizations (71%), 10-49 organizations (84%), and among those following 50 or more organizations, 98% identify as local.

Moreover, by identifying local citizens as information recipients, we find that users following local organizations on Twitter differ with respect to their level and position of embeddedness within the community information infrastructure. Local media accounts on Twitter, including television, radio, and news organizations, feature the most followers among the categories of local organizations we catalogued. However, the vast majority of users following only one or two local organization on Twitter (160k+) disproportionately curate media organizations within their social networks. Thus we see local citizens within this majority as information recipients weakly embedded within the local information infrastructure, and positioned so as to receive information predominantly from local media sources.

Additionally, we identify a sizeable minority of users (20k+) who curate their social networks to follow multiple and various kinds of local organizations on Twitter, to include not only media accounts, the most followed organizations in the community, but more citizens' associations and civic organizations relative to the majority of weakly embedded citizens. Thus we see this minority of moderate, high, and extreme follower as information recipients strongly embedded and distinctly positioned in the information infrastructure of the community.

We thus see value in developing ST for community preparedness and resilience-building to better map the information infrastructures existing in local communities in order to support local emergency communication planning. For the city in which we deployed ST, for instance, the Twitter accounts of emergency services collectively have a total of 16k followers. Among these, the municipal police department, which routinely posts public updates of crime and traffic incidents, has the most (8k). In comparison, the two local television stations and newspaper each have over 15k followers. Through the analysis of user curation behaviors, the followers of these organizations occupy different levels and positions within the information infrastructure of the community.

In the case of emergency situations, however, civic and emergency services will be called on to disseminate important public warnings and situational updates. Previous studies find that municipal governments and emergency managers often lack guidelines for emergency communications planning guidelines that might result in effective social media dissemination strategies (Huston et al., 2015; Rice and Spence, 2016). ST stands to inform the development of general and community-specific guidelines for emergency communications. Our exploratory deployment of ST leads us to three preliminary conclusions about our method and the particular information infrastructure that we have studied. First, in our sample, local information recipients that only followed one unique category are more commonly users that live outside of the geographic area of interest.

When using ST to identify information that local citizens are sharing, their inclusion may be problematic, however, if using ST to push information to local citizens, this group should certainly not be eliminated, as they constitute the majority of identified local citizens despite being the least connected. Second, while the media may attract a great many followers, these followers may only be loosely embedded in the information infrastructure of their community and may not be aware of information shared by emergency services directly. Lastly, in this community, the followers of citizens' associations appear to be highly embedded individuals and may be useful sources to seek information from during an emergency.

LIMITATIONS AND FUTURE WORK

These findings suggest ST holds promise for uncovering citizens in a geographic location and revealing the local organizations from which they receive information. However, important limitations must be considered that require future work. First, we acknowledge that additional parameters to refine the aggregated datasets of local organizations and followers will require further exploration. One limitation of this work is that despite our best efforts to identify local organizations using community directories, online search, and recommendation system suggestions, additional efforts must attempt to achieve more comprehensive catalogues of local organizations. The 195 local organizations used in this analysis are likely a non-comprehensive list of local organizations within the municipality on Twitter. Future research should focus on looking for organizations that may be fragmented from the primary information infrastructure.

Second, our analysis only recognizes organizations as streams of community information, however, alternative or multiple information streams might be more appropriate. Social networks among local citizens remain absolutely critical as information channels on social media platforms. Moreover, we recognize that prominent individuals can be more influential than organizations in the creation and dissemination of information through social media. We see the concept of ST as suitable for cataloguing both salient citizens and organizations as a geographic "ground truth" in relation to which the location of users following these local personal or organizational accounts can be evaluated and inferred.

Third, and lastly, our effort to ascertain users' locations through the use of available profile location information requires further methods of evaluation. We see as an immediate opportunity the collection and analysis of geotagged tweets posted by users following local organizations. In this regard, users with geotagged posts might be identified as local citizens according to three separate localness metrics defined by Johnson, Sengupta, Schöning, and Hecht (2016): if the user posts tweets in the municipal locale at least n-days apart (n-days metric); if the majority of the user's tweets occur in the locale (plurality metric);or if the geographic median of all the user's tweets falls within the locale. These metrics could be compared among and between users following the same number of organizations as well as categories of organizations. Such an analysis would further our understanding of the relationship between user information curation behavior and geographic location.

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The key role of animation in the execution of crisis management exercises

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ABSTRACT

The organizers of crisis management exercises want scenario credible and pedagogical from the beginning until the end. For this reason, they call on an animation team that can use different communication channels. The aim of this article is to understand the different types of animation by analyzing the professional experience of the facilitators and the type of casting that can be done. Finally, a definition of four levels of animation is proposed. These levels are associated with different types of messages and rhythm settings. The main objective is to improve the execution of the scenario during a crisis management training.

Keywords

Crisis, training, animation, facilitator, scenario

INTRODUCTION: CRISIS MANAGEMENT EXERCISES

Crisis management exercises goals

Crisis management exercises are tools that enable organizations to practice in managing crisis situations. Trainees can acquire or consolidate reflexes and decision-making processes. The implementation of the exercises is therefore crucial to ensure the proactive management of crisis situations.

Governments are aware of this. So, they have put in place crisis management policies to force organizations to train and practice through simulations. In France, a law in 2004 encourages all the stakeholders, from civilian to general staff, to train with exercises. The hazardous industries have to train at least once a year. In Ireland, since 2002, the civil defense members have to train themselves (Civil Defense Act 2002/2012). The Federal Emergency Management Agency (FEMA) offers a training program throughout the National Incident Management System (NIMS) for all people involved in emergency management. This program was created with the Post-Katrina Emergency Management Reform Act in 2006. The European Flood Directive (2007/60/EC) provides a program of measures wherein is included non-structural measures as training for preparedness for better crisis management.

Although crisis management requirements change, we know that the regulatory obligation is not necessarily a sufficient lever for the implementation of a crisis management policy (Gralepois et al., 2015). As indicated by Gralepois and Douvinet, some factors may hinder the frequent implementation of exercises. These factors include a lack of internal skills to organize training, insufficient financial resources to hire consultants, difficult collaborations with government departments or a lack of a culture of risk that raises the common consciousness to practice to manage emergency situations.

Despite these negative aspects, it is important to note that when crisis management exercises are implemented, they are hailed. Indeed, organizations can derive real benefits from different points of view:

- From an organizational point of view, they allow the actors of crisis management to meet each other, to learn how working together and to organize the information diffusion;
- From a planning point of view, exercises are wonderful tools for detecting defects in crisis management plans (e.g. missing or incorrect information, organization of the plan that can be improved…);
- From a practical point of view, the actors have the opportunity to test the spatial layout of the crisis unit (furniture, placement of players, posting ...).

The different phases: from preparation to debriefing

Based on different works, it is possible to establish the course of a crisis management exercise (Lapierre, 2016; Morin and Jenvald, 2003; Tena-Chollet, 2012). We can retain 8 steps (figure 1):

1. **Planning**: this phase enables organizer to inform participants if it is necessary and to manage administrative aspects of the preparation of an exercise (Morin et al., 2004).
2. **Needs assessment**: identifying the needs of learners in terms of skills is essential for training to be relevant (Salas et al., 2006).
3. **Establishment of pedagogical objectives**: during the preparation of an exercise, it is necessary to define the pedagogical objectives that correspond to the needs of the learners (Morin et al., 2004). Then, these objectives can be used to produce an observation grid (Lapierre et al., 2015).
4. **The scriptwriting**: a crisis scenario must be drawn up before the exercise. It can be more or less established but it must be credible (Walker et al., 2011). It lays the basis of the exercise: the location, the hazards, the kinetics and the type of the crisis cell that will be simulated (Gaultier-Gaillard et al., 2012). The number of learners and their profiles should also be taken into account during this phase.
5. **The briefing**: it enables to introduce to all the learners the objectives of the exercise, its conventions, the available resources and the evaluation criteria and to remind it to the facilitators (Gaultier-Gaillard et al., 2012).
6. **The execution of the scenario**: it can be carried out in different ways, but there is often an animation team that transmits scenario's messages to the players (Gaultier-Gaillard et al., 2012). To ensure the quality of the training, the execution of the scenario has to maintain the credibility according the decisions made by the training; we call it the harmonious evolution. During the exercise, there may be observation grids filled out by evaluators (Lapierre, 2016) and there may also be a system for tracing the activity of the learners (Carron et al., 2007)
7. **The debriefing**: it is considered as an important step in learners' learning (Lapierre, 2016). It can be technical as well as psychological in the context of crisis management. This dual approach makes it possible to restore the practice of technical or non-technical skills during hot or cold debriefing.
8. **The analysis**: it can be carried out to evaluate the training as a whole and the impact it has had on the learners (Tena-Chollet, 2012) and also to provide a cold analysis of the learner's journey from a pedagogical point of view with advice for the continuation (Salas et al., 2006).

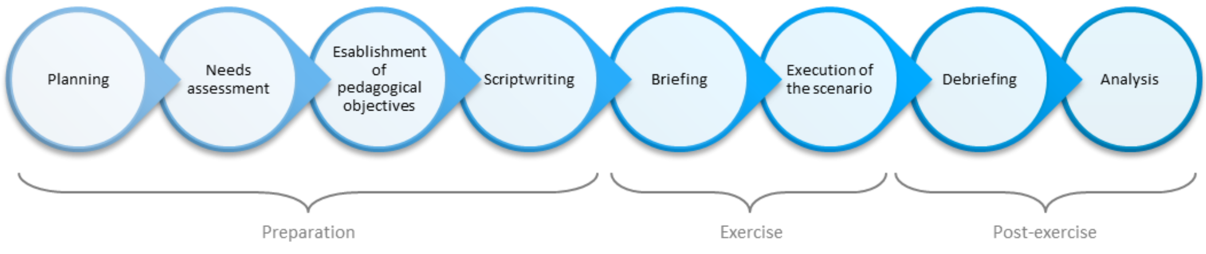

Figure 1 The 8 steps of a crisis management exercise

We notice that steps of planning, needs assessment, establishment of pedagogical objectives and scriptwriting constitute the preparation phase of an exercise. Also, the exercise itself begins during the briefing, when the learners already devote all their energy to the smooth running of the training. Then, it is the execution of the scenario that completes the exercise phase. Finally, the last phase is post-exercise and it is formed by debriefing and analysis.

The organizers of exercise sessions in France

In France, there are different types of trainers. Here, it is question to introduce some of them and not to mention an exhaustive list. The french offer can be distinguished in 3 main areas of offer: the public, the research and the private one.

Training from state organizations

Within the public offer, there is INHESJ (National Institute of Advanced Studies of the Security and Justice) that is place under the supervision of the Prime Minister. It organizes exercises for the prefectural corps, the police force, firefighters and schools. INHESJ, created in 1989, offers a varied range of training courses in crisis management from different origins: major risks, CBRN (Chemical, biological, radiological and nuclear), political or media. Indeed, INHESJ offers seminars, theoretical lessons and simulation exercises in crisis management. It is important to note that the institute also works on issues of economic security, security and justice.

Another recognized crisis management trainer is the ENSOSP (The French Academy for Fire, Rescue and Civil Protection Officers), under the supervision of the French Minister for Civil Security. Since 1977, ENSOSP has trained professional and voluntary firefighters, as well as civil servants, business executives and French and foreign experts to better understand the operating of fire and rescue. According to article 2 of the founding decree 7th June 2004, ENSOSP is also in charge of (i) facilitating the network of firefighter schools, (ii) research, studies, evaluation, foresight, technological monitoring and dissemination of information, and (iii) developing international cooperation in the fields of training and research. In order to meet these objectives, ENSOSP has life-size simulators with technical platforms, a real city, the SIMURge – a simulator of emergency medical emergencies, tactical operational rooms and the reproduction of operational command center. There are also virtual reality simulators for training on risk as chemical, radiological, flood, urban fire, and demonstrators of physicochemical phenomena.

The Center of Valabre is approved by the Ministry of the Interior to provide training in first aid, chemical and radiological hazards, off-road driving, rescue, clearing, emergency rescue and mountain rescue. To fulfill its missions, the center has maneuvering grounds, a diving center, training rooms and simulation software for forest fires.

French prefectures also organize exercises in the frame of ORSEC plans that are emergency plans in case of disaster. So it is the responsibility of the French organization to organize the training schedule. To design crisis management training there is no training organism associated and the prefectures are autonomous.

Training from voluntary organizations

Among the association dealing with crisis management, there are IRMa (Institute of Major Risks), CYPRES (Information center for the prevention of major risks) and IFFO-RME (French institute for trainers in major risks and protection of the environment). The missions of IRMa and CYPRES are fairly close: on the whole they contribute to the preventive information of the populations on the major risks. They also train, advice and support local decision-makers when planning crisis management. Then they offer an information and legal monitoring. CYPRES also supports industrialists. As for the IFFO-RME, it has an agreement with the Ministry for Sustainable Development, the Ministry of National Education, the General Board for Civil Protection and Crisis Management and the Ministry of Agriculture, Agri-food and Forestry sectors. The objective of IFFOR-ME is to integrate the culture of risk into the culture of the citizen by developing and running a network of trainers on the issue of major risks.

Training from research organizations

Among the public organization, there are teams of researchers working on improving training in crisis management. The formations constitute part of their protocol of experimentation. Two laboratories offer these formations: Mines Nancy and Mines Alès. Mines Nancy has developed a software called iCrisis^{TM}. It supplies a platform that is mainly used to train students. It is used to simulate crisis management with industrial crisis (Gregori et al., 2009). Interactions between crisis units are played and players can train to make decision under pressure and to manage a crisis at a strategic level. The scenario, in iCrisis^{TM} is not fixed at the outset: only one frame is defined beforehand during a discussion between facilitators. All the messages are exchanged through the web system (Verdel et al., 2010). This system is good at raising conscience of what is a crisis but in the meantime it does not aim to enhance the individual or collective resilience.

As for mines Alès they have a crisis management training platform that reconstitutes the environment of a crisis cell to facilitate the immersion of players. A system called Simulcrise was created to support during the scenario processing. It is based on a distributed multitier architecture with the use of a multi-agent system. This system requires the modelling of agents with the definition of the global system and their expected behavior. An animation team acts as an interface between players and agents.

Training from private organizations

There are many private trainers. The offer is therefore very varied: there can be theoretical courses, exercises on table, simulations or exercises real life. Topics covered include social networks, media, natural hazards, CBRN risks, industrial risks, etc. Some of them have made crisis management training their core business as Argillos or Resiliency while others made it a secondary offer as Predict Service or Mayane.

ANIMATION SETTINGS

In all the training offers cited above, it can be seen that in order to train a crisis management group at strategic scale, it is necessary to call on an animation team to simulate the actors in crisis management outside the crisis unit. The role of the animation team is to run through a crisis scenario to mobilize skills, knowledge and to "force" trainees to make decisions in degraded situations.

Regarding the animation, the organizer of an exercise must clarify several points:

- Specifying the communication channels to be used;
- Defining the number of facilitators;
- Distributing the roles.

Thus, in this part, we shall endeavor to study the different choices which appear for these three points. In our research work we have acquired experience in terms of animation management thanks to the organization and the observation of several crisis management exercises. We have carried out this analytical work thanks to the state of the art and to our experience.

The communication channels used by the facilitators to communicate with the trainees

In a real crisis situation, crisis managers will have at their disposal different means depending on the state of communication networks to interact with actors outside the crisis unit. The first way is probably the phone, followed closely by the internet mail. In recent years, social networks have also to be considered in addition to the media. The crisis unit will also use fax, in particular as a redundant mean, as it is the case in the French administration. And finally, some information will be available via websites, such as that of Météo France (the French national weather service).

As part of an exercise, each of these means is used in the exercises, more or less. In literature, we find that the use of telephone, email, fax but also facsimiles (a copy or reproduction of a document) is recommended (Boin, 2004). In the INHESJ exercises (Dautun et al., 2011), at the mines Alès (Tena-Chollet et al., 2016), but also in Mines Nancy (Verdel et al., 2010) the phone and email are used. Sometimes a printer is used to simulate the fax and to send facsimiles (Tena-Chollet, 2012). In some exercises, a facilitator can make an oral intervention for trainees in the room. In the latter case, we call the media used the voice.

The aim here is to present the advantages and disadvantages of using each of the media in the animation of a scenario (Table 1). The comparison of the communication channels was carried out following the exercises we have organized and observed.

In a crisis exercise, it is certainly interesting to vary the communication channels to enjoy the benefits of each media. This also makes it possible to overcome the limitations encountered, less to suffer less of disadvantages and to raise awareness among the learners on the different media that can be used a crisis situation.

	Advantages	Disadvantages
Phone	Media actually used in a crisis unit (immersive) Interaction between actors more interactive and spontaneous. If the system enables it, exchanges can be recorded.	If a facilitator plays several roles, the same voice will be associated with different actors of crisis which creates a bias of credibility. It must be equipped with a number of phones.
Email	Media actually used in a crisis cell (immersive). Exchanges can easily be recorded and analyzed. Different roles can be assumed by the same facilitator who can take time for reflection to answer.	Exchanging by email can be time-consuming (in terms of writing or reading). Email is less interactive than the phone. It must be equipped with computers and internet.
Social networks	Media actually used in a crisis cell (immersive).	If trainees use the real social networks, they use key words as “exercise-exercise-exercise” that makes the training less immersive. And if trainees forget to do it, there is danger of confusion between situation of exercise and real situation. The photos will be photos of past events that can be recognized (loss of immersion).
Medias	Sensitize to media training. An interview (telephone or face-to-face) can easily be reconstructed. Elements can be prepared in advance (video from a TV or soundtrack of a radio).	A TV or radio antenna is tedious to reconstitute and to simulate.
Fax	Allow the player to keep a paper record of the information sent.	Difficulties in updating the document in the course of the exercise according to the answers of the learners.
Facsimiles	Can be prepared in advance. Provides contextual and understanding of elements of the scenario while enhancing immersion.	Difficulties in updating the document in the course of the exercise according to the answers of the learners if complex layout (a press, vigilance bulletin ...) or need for modeling (risk map).
Voice	Does not require special means.	Unrealistic exchange and strong intrusion from the facilitators.

Table 1 Comparison of the communication channels

Crisis management professional facilitators versus non-professional facilitators

In a methodological guide on exercises, authors indicate that it is necessary to have leaders from the crisis management professional world (Mercan et al., 2009). They add that as far as it is possible, the organizer has to choose facilitators who are in the same trade as the trainees. They add that the facilitator must play emotions if the scenario specifies it. It is understandable that facilitators must have real talents of actors (Boin, 2004).

These recommendations therefore can require the mobilization of a significant number of crisis management professionals. For exceptional and punctual exercises, it may be possible to do so despite the difficulty of the often busy agendas of all crisis management professionals. Due to these difficulties, training organizers also have recourse to non-professional crisis management personnel with a good knowledge of the ins and outs of crisis management (consultants, teacher-researchers and crisis management students). Non-professional crisis management personnel can be used to train and can have good knowledge on pedagogical engineering.

Then, a crisis management training organizer can wonder whether he should involve professionals or non-professional to animate the scenario. To accompany him in this choice, it is here proposed to present the advantages and disadvantages of each in order to make an informed choice.

The crisis management professional facilitators

Concerning professional facilitators, it goes without saying that they will be completely credible in their role, which will reinforce the realism of the exercise. Also, the learner will consider them legitimate, that is to say that their word will not be called into question. The organizer will not need to prepare an animation help sheet (this is a sheet that contains background information on the crisis situation and information on the role for the facilitator to answer credibly). Indeed, thanks to his professional experience, the facilitator can improvise if necessary. Finally, facilitators' briefing on the scenario and exercise will not require much time.

However, it is necessary to be aware that the improvisation of a facilitator can lead to a loss of control of the scenario. This means that if the training organizer wishes to make the trainees work on a particular point (e.g. the difficulty of mobilizing staff in the middle of the night) and the facilitator improvises and replies that all the staff have been contacted and will be available within 20 minutes then it will not be possible to implement the learning situation. Therefore, if the organizer wishes to propose some crisis management obstacles to the trainees, it is necessary to inform the facilitators beforehand so that the pedagogy of the exercise is assured.

In other words, the follow-up of the achievement of pedagogical objectives by trainees can be easier for professional facilitators that are used to animate than for professional facilitators that animate for the first time. It is therefore a question of raising the awareness of crisis management professionals to the interest of training and what facilitates the acquisition of skills. In fact, to validate pedagogical objectives, the discussion between facilitators and trainees would be less natural and spontaneous because the facilitators have to investigate among the trainees. This often results in reality biases where the facilitator will accompany the trainees in their decision or labor some points.

Finally, some organizers use specific tools to manage animation (Dautun et al., 2011; Tena-Chollet, 2016; Verdel et al., 2010). These tools can be more or less intuitive and therefore require a certain investment on the part of the facilitators to appropriate it. In some cases, some crisis management professionals may be reluctant to use these tools. This lack of interest may be due to reluctance to change (some have their heart set on using their "old method").

The crisis management non-professional facilitators

Here we mean by crisis management non-professional facilitators, facilitators whose primary job is not to be in charge of crisis management. However, their first job of these people revolves around crisis management: trainer, consultant, teacher-researcher or students. As opposed to crisis management professionals, this type of facilitator will not have the same legitimacy to perform certain roles and improvisation will be more difficult. The organizer of the exercise will then have to produce an important work to overcome these limits and take the time to brief the facilitators.

However, appealing to non-professional crisis management facilitators has several advantages. The first is that a non-professional facilitator who is not attached to his professional experience will focus more on the integrity of the scenario throughout the exercise, i.e. he will endeavor to ensure pedagogical aspects while he will keep in mind to that the scenario had to evolve in a harmonious and credible way. The organizer of the exercise will then have more ease to propose a tool to manage animation and the facilitators may be more accommodating to make every effort to follow the achievement of the pedagogical objectives by the learners.

Thus, if the facilitators come from the same entity (training institute, consulting firm, research laboratory), it seems easier to bring everyone together for the preparation and more generally for the exercise.

Comparison between crisis management professional and non-professional for scenario animation

In table 2, the main advantages and disadvantages stated above have been recorded following the organized and observed exercises. It should be kept in mind that in any cases it is advisable to use the same facilitators from one exercise to another. Indeed, the mechanisms of an exercise will be better assimilated and the gradual disadvantages will be erased.

	Advantages	Disadvantages
Professionals	- Credible et legitimate - Improvisation possible - Less preparatory work	- Risk of loss of control from a scenario point of view due to improvisation and more spontaneous speech - Reluctance to use animation tools - No monitoring of achievement of pedagogical objectives - Less availability upstream of the exercise
Non professionals	- Controlling the evolution of the scenario - Use of animation tools - Monitoring of achievement of pedagogical objectives - Availability upstream of the exercise	- Risk to be less credible and legitimate - Difficulties to improvise - Important preparatory work - Need to brief facilitators

Table 2 Comparison between crisis management professional and non-professional for scenario animation

Definition of the different types of role distribution

When the organizer of an exercise works on animation, he must wonder how he will distribute the roles between the different facilitators. Obviously it depends on practical conditions such as the number of available facilitators for the exercise, the maximum number of facilitators that can be mobilized due to reasons as welcome conditions, economic ease and the number of roles to be simulated. Ideally, when the organizer has the choice, he might wonder if he prefers to distribute a role by facilitator (single-role distribution) or distribute several roles to the same facilitator (multi-role distribution). To answer this question, the two cases of distribution we have used in our exercises and we observed are analyzed.

The single-role distribution

In the case of a single-role distribution, it will be easy for the facilitator to concentrate on the role he has to ensure and thus to carry out the coherence in his exchanges with trainee(s) with whom he will be in contact.

Even if these advantages are not negligible, there are disadvantages. The first is that if there are many roles to be ensured, then the animation team will be composed of many members. Also, if the facilitators are located in the same room, the organizer can expect the animation room to be noisy and the facilitators would have difficulties in concentrating and communicating with each other.

It will also be difficult to have a shared vision of the scenario throughout the exercise if the number of facilitators is high. Consequently, it may happen that a facilitator doesn't get information and subsequently transmits discordant or even absurd elements. Thus, a harmonious evolution of the scenario will not be guaranteed.

Finally, if the facilitators cannot follow the evolution of the scenario, it is not possible to certify that the pedagogical situation and the follow-up of the associated objectives can be established.

The multi-role distribution

The first advantage of a multi-role distribution is the reduction in the number of facilitators needed. Indeed, by assigning several roles to one facilitator, the human resources necessary to train the animation team are reduced. In this way, the ratio of the number of facilitators per number of learners is reduced. Therefore the atmosphere and the sound level in the animation room will be calmer. In this way, it will be easier for facilitators to communicate with each other and share a common vision of the scenario and its evolution.

The disadvantage of giving several roles to the same facilitator is the cognitive burden that this generates. The facilitator must sometimes respond to many requests from the trainees. Then, he will need to have the gift of ubiquity while being ubiquitous as the task is sometimes complicated.

Comparison between single-role distribution and multi-role distribution

The advantages and disadvantages of both types of casting are summarized in table 3. From an organizational point of view, multi-role distribution seems to be more relevant because it limits human resources. In addition, if the organizer has to pay the facilitators, the economic model will be more interesting. After all, with experience, animating several roles simultaneously could become easier.

	Advantages	Disadvantages
Single-role distribution *(1 facilitator per 1 role)*	-The facilitator can focus on his role - Coherence of the facilitator's speech throughout the exercise	- Noisy animation room due to significant numbers of facilitators - Difficulty to have a shared vision of the situation - Difficulty to ensure a harmonious evolution of the scenario - No monitoring of achievement of educational objectives
Multi-role distribution *(1 facilitator per many roles)*	-Number of facilitators reduced -Smoother atmosphere -Shared vision of the situation and possibility of harmonizing the evolution of the scenario	- Difficulty to simulate several roles simultaneously (excessive solicitations) - Risk to make the scenario less credible

Table 3 Comparison between single-role distribution and multi-role distribution

The importance of the animation master

The animation team must take on a heavy task regardless of the type of distribution of roles and whatever the expertise of the facilitators. The task for each facilitator is heavy going. For this reason, it is recommended to ask a person from the animation team to play the animation master (Sénateur et al., 2008). This person, free of any task of animation can guarantee the evolution of the scenario by directing the facilitator like a conductor to carry out the situation of learning (Dautun et al., 2011; Sénateur et al., 2008). He can also support facilitators by giving them elements that they lack.

PROPOSED DEFINITION OF ANIMATION INTO 4 LEVELS

Definition of the 4 levels of animation

In the methodological guide on executive exercises and field exercises, the authors define two levels of animation: low animation and high animation (Mercan et al., 2011). The definitions of these two types of animation are here supplemented. The analysis of the crisis exercises organized within the framework of this research enables to define two additional levels of animation. The definitions of the concomitant animation and the animation in situ are established in the context of our research work.

The low animation injects events and incidents that come from the lower echelons compared to the crisis unit simulated by the trainees. For instance, if trainees perform a crisis unit at the communal level the low animation would simulate mainly the municipal agents constituting the field teams in charge of missions about security, emergency accommodation and logistics. Therefore, the low animation must be accountable to the trainees for the actions taken.

The high animation simulates crisis management actors who are hierarchically above the crisis unit simulated by the trainees. If we take the previous example, the high animation would ensure higher roles of authority such as the Prefect. The high animation will also simulate the actors of the crisis management whose speech cannot be questioned by the trainees. Also in the event that learners should manage a crisis unit at the communal level, high animation could simulate firefighters and the weather service.

Beyond these two levels of animation, the research we conduct encourages us in the definition of two additional levels of animation. The third level of animation that can be observed is **the concomitant animation**. This level corresponds to all the roles that have no hierarchical relationship with the crisis unit played by the trainees. For example, in this level, we can find the media and the local residents. It is all the stakeholders in a crisis situation that do not maintain a subordinate relationship with the simulated crisis unit.

And finally, the last level of animation is at the margin of the three previous levels. It corresponds to **the animation in situ**. It is in fact a person who is in the trainees' room and who will intervene either to guide the trainees in their management of the situation or to warn them of new events or elements of decision. This person can be here only to do these interventions or it can be an observer. The choice of who will assume the animation in situ depends on the numbers of facilitators, their training experienced and the pedagogical objectives of the exercise. Animation in situ is not often encountered because it takes a tactfulness person with experience in crisis management that can be both a safeguard and a pedagogue.

The four levels of animation are shown in figure 2.

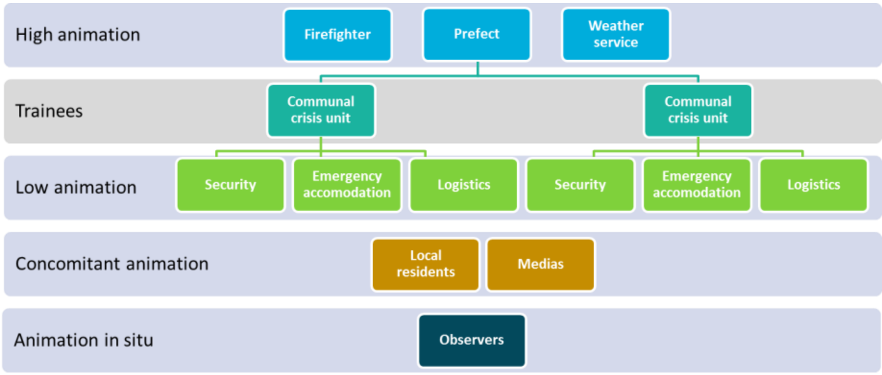

Figure 2 Illustration of the 4 levels of animation those are possible during a crisis management training

Settings of the four levels of animation

Each animation level will be the subject of different parameters. We define here the communication channels to be privileged, if professionals or non-professionals are needed and the type of distribution to favor.

Link between the animation levels and the different communication channels

As seen previously, the communication channels are various. The ideal is to use in the simulation the communication channels usually used by crisis actors. If we take the example of an exercise where trainees simulate a communal crisis unit, the low animation that simulates the field teams will communicate mainly by phone. The use of e-mail can also be considered according to the crisis context.

The high animation could be led to use:

- Phone and e-mail : the prefect, firefighters or weather service are led to dialogue by phone or even by mail;
- Facsimiles: document imitating meteorological vigilance maps can be used for instance;
- Voice: the prefect or firefighters can burst into the communal crisis unit.

The concomitant animation, for its part, will have to use a multitude of communication channels:

- Phone: residents and journalists can use it to question the crisis unit;
- Social networks: they enable each citizen and entity to disseminate information on the current crisis;
- The media: they will be used to inform the crisis unit or to disseminate the information gathered during previous interviews;
- The voice: a journalist can burst in the communal crisis unit.

Animation in situ can intervene by giving a facsimile or by appealing to the trainees orally.

Link between the animation levels and the degree of professionalism required

If we keep the previous example, the level of professionalism "demanded" will be different according to the level of animation.

For low animation, the facilitators require a good knowledge of the territory and the available resources because these are more operational roles. However, if the information is sufficient and if they are well trained, non-professional facilitators can simulate the low animation.

For high animation, depending on the roles it is easier to call on professionals as it is difficult to appropriate some functions. If we take the example, the role of firefighters will be easier to simulate by a member of the civil security than by a non-professional. Again, if non-professional facilitators are well-informed and trained, they can also simulate the roles of high animation.

For the concomitant animation, the roles can be assumed by non-professionals. Indeed, it seems within the reach of all to simulate the local residents for instance.

Animation in situ does not require a particular level of professionalism. However, the facilitator must have the necessary pedagogical skills to intervene in a relevant way.

It must be added that the assignment of roles must also take into account the skills, knowledge and personalities of the facilitators so that the animation is as relevant as possible.

Link between the animation levels and the type of role distribution

Associating a type of role distribution according to the level of animation can be done if one is able to estimate the level of solicitation of trainees for a role. With our example the low animation represents a major operational aspect of the crisis unit. It will be easier for the facilitators if they can devote themselves to their roles. The mono-role distribution seems to favor here.

Similarly, the high animation will have different level of solicitation. Depending on the context of the crisis, a prefect or a weather service expert may be requested more punctually, while a civil security representative may be contacted more frequently. It may therefore be envisaged to assign several roles to facilitators simulating the prefect or the weather service expert and to assign the sole role of firefighter to a facilitator.

The roles of the concomitant animation can be cumulated with other roles and even distributed among several facilitators. Indeed, the interventions of the concomitant animation are often punctual and it is not pertinent to ask a facilitator to concentrate on the role of a journalist or local residents. Also, it may be appropriate to divide between several facilitators the interventions of the local residents because this allows varying the voice and sharing the load. Therefore, multi-role distribution seems to be relevant for concomitant animation.

Animation in situ is not affected by the type of role distribution. It is mainly a pedagogical intervention and not a simulation of crisis actors.

However, it adds to this analysis summarized in the table 4 that the person in charge of the animation management that she must adjust according to her needs and resources all the setting of the animation. Under restricted conditions, concessions will have to be made.

	Low animation	High animation	Concomitant animation	Animation in situ
Communication channels	Phone, e-mail	Phone, e-mail, fax, facsimiles, voice	Phone, e-mail, social networks, medias, voice	Voice, facsimiles
Degree of professionalism required	Non-professionals	Professionals and non-professionals	Non professionals	Non-professionals
Type of role distribution	Single-role distribution	Single and multi-role distribution	Multi-role distribution	Not concerned

Table 4 Link between the animation levels and the animation settings

Characterization of these levels of animation

During the development of a crisis management training, pedagogical objectives must be established (Lapierre, 2016). They constitute the pedagogical foundation of the training. The scenario that is set up must create learning situations that mobilize the learners in this sense. After analysis, it will then be possible to determine whether the learning objectives have been achieved by the trainees and whether the exercise was actually a formative one.

Link between the animation levels and a typology of messages

From the point of view of the educational sciences, each level of animation will solicit the trainees in different ways through messages of the scenario. In our work, we define three types of messages: the injection message, the control message and the atmosphere message.

The first possibility is **the injection message**. In this kind of message, the facilitator will state situational elements with the trainee in order to inject pedagogical objectives. For example, a member of low animation will pass information to the trainees on a certain number of issues impacted. The trainees will be expected to do several actions: communicating within the cell this information, recording it, and dealing with it if necessary. The second possibility is **the control message**. This kind of message is more a dialogue in which the facilitator will judge whether the objective is achieved. If we take again the last example, the facilitator will ask a trainee the actions that have been undertaken in relation to the impacted issues. He will be able to check if there is a takeover that has been done or if this information is gone down the train. Finally, the third and last possibility is **the atmosphere message**. In these messages, there is no pedagogical goal. The main purpose is to simulate credible exchange to immerse the trainees in a crisis situation.

In a simplistic way, it is possible to correlate the animation levels with the message typology defined in the previous paragraph. Indeed, the high animation, due to its position, is going to send mainly control messages. Conversely, the low animation will mainly send injection messages. Control messages can also be assumed by the low animation when it is about receiving requests from trainees for setting up of actions (thein it is about checking they have made a decision and that they try to put it in place). As for concomitant animation, they can ask questions to the trainees that stand for control messages. They can also give diverse information to trainees, so it will be injection messages. Finally, the members of the concomitant animation will be able to do messages atmosphere messages.

The role of animation in situ is somewhat outside the objectives of an animation team, so it doesn’t seem to be appropriate to relate scenario messages with pedagogical scope to this type of animation.

The animation rhythm

Once the author of the scenario understands how animation and message can be articulated, he must establish when these messages will be send to the trainees. To define these moments, two parameters are used:

- The first one is the phase. The scenarios used in crisis management exercises can be divided into 3 phases: an initial phase during which trainees take their mark, a median phase during which many decisions have to be made and finally a final phase during which the actions are set up and the situation is beginning to be over.
- The second is the frequency. In order to be credible, the organizer can wonder whether the message has to be transmitted once or several times.

It is then to situate the message in one of these three phases and to determine whether its frequency is high (e.g. every 5 minutes) or slower (e.g. every hour).

Schematically, it is necessary to initiate a situation and leave time for the trainees to react before they can begin doing anything. Based on this philosophy, elements of reflection are proposed here. It is established that the high animation will send control messages from the middle phase to the end of the final phase.

The low animation, responsible for the feedback from the field, can send injection messages from the beginning of the exercise to the final phase. It will have to deal with an increase of these messages in median phase due to sending injection messages at the same time that sending control messages.

Finally, the concomitant animation can ensure the 3 types of messages during the 3 phases. It is likely to intervene throughout the scenario at frequencies more or less important.

These elements of reflection on the rhythm of the interventions of the different types of animation are represented in figure 3.

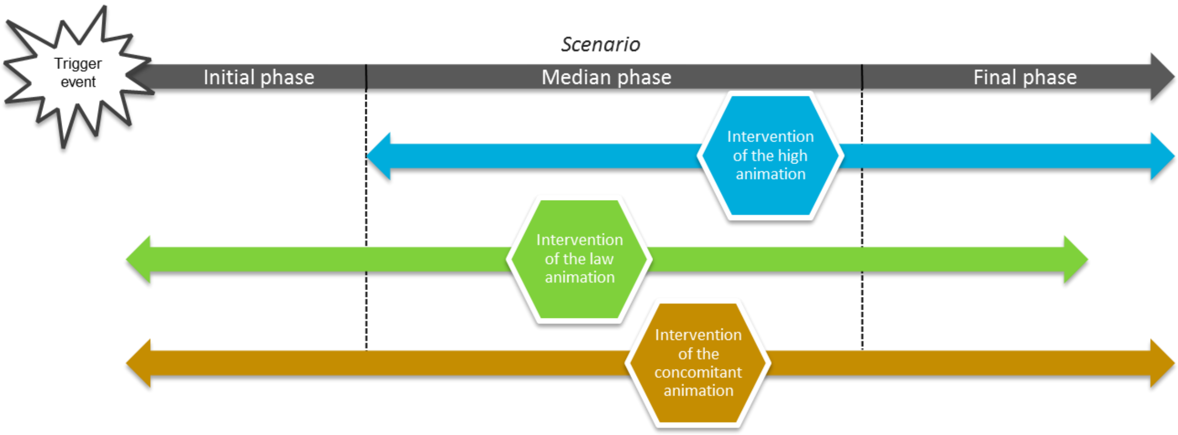

Figure 3 Interventions of the different levels of animations in a crisis management scenario

It is necessary to moderate these remarks by taking into account the preconditions for sending a message (the realization or not of an action, a strong anticipation or an error of appreciation from trainees...). It also seems necessary to detail these remarks for the different educational objectives that are expected. Thereafter, it will be necessary to work on each actor of the crisis management to identify all the influences that can have on the scenario. This will make it possible to better understand the impact of the role of the facilitator on the scenario and on the pedagogical objectives while preserving scenario coherence.

CONCLUSION

The aim of this research is to make crisis management exercises more efficient from a pedagogical point of view. The position here is to better understand the ins and outs of the animation thanks to the different mechanisms that relate to it like the communication channels used by facilitators to send messages, the choice of the type of facilitators (professional or not) and the casting that can be made between the members of the animation team. The characterization of the animation through the definition of different levels and the linking of a typology of message makes possible to tend towards a more efficient animation in terms of pedagogy.

PROSPECTS

The execution of a crisis scenario is not easy. It is from this observation that the work presented in this article has begun. It is the first step before making execution of scenario more harmonious and interactive. The desire is to deepen the link between the educational objectives, the type of animation, the roles and rhythm parameters. Once it could be done, it will be about working on the content needed by the facilitators to simulate their role more really while controlling the information he is giving.

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Applying Usability Engineering to Interactive Systems for Crisis and Disaster Management

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ABSTRACT

Crisis and disaster management are increasingly characterized by interactive systems intended to be valuable support for professionals and volunteers in preventing, preparing for, responding to and recovering from major incidents and accidents. Therefore, usability in terms of safe and efficient usage of computer-based solutions becomes a crucial factor for successful crisis and disaster management. In order to ensure usability, it has to be addressed systematically throughout any development process. In this paper, established engineering approaches to crisis and disaster management systems are summarized. Subsequently, resemblances (e.g. diversity of users and devices) and differences (e.g. scalability) between safety-critical contexts of medical device design and crisis management are outlined. Following this, recommendations for applying usability engineering processes to disaster management are derived from standards and guidelines according to medical device design (IEC 62366-1:2015, ISO 14971:2007). Particularly, relationships and interactions between usability engineering and risk managements measures (e.g. hazard-related use scenarios) are described.

Keywords

Usability Engineering, Risk Management, Medical Devices, User-Centered System Design

INTRODUCTION

Information technology varying from wearable devices (e.g. smartwatches, smartglasses) to stationary command and control rooms with multiple screens and various workstations have *"a tremendous potential for increasing efficiency and effectiveness in coping with a disaster"* (Meissner et al., 2002). However, it can only be brought to bear, if users will be able to handle their tasks successfully taking as little time and cognitive load as possible. This is a major challenge because *"an [user] interface is still an intermediary between the user's intent and execution of that intent. As such, it should be considered at best a necessary evil because no matter how fluid, it still imposes a layer of cognitive processing between the user and the computer's execution of the user's intent"* (van Dam, 1997). In the worst case, it could either prevent crisis managers, first responders, volunteers or the general public from using or trusting such computer-based solutions or cause problems resulting in delayed or improper actions.

In this regard, *usability* as *"the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO, 1998) is a crucial factor for suitability of interactive system in any safety-critical domain. It has to be addressed and ensured systematically throughout any development process. Necessary measures include context of use analysis, human-machine task allocation, human-machine cooperation, interaction and interface design as well as usability evaluations (Mentler, Reuter and Geisler, 2016).

In the following section, two research questions will be addressed:

1. Which specific engineering approaches have already been applied to the development of crisis and disaster management systems?

2. Could recommendations for applying usability engineering to crisis and disaster management be derived from ones established in the safety-critical context of medical device design? If yes, which are they?

Firstly, the topic of (usability) engineering approaches to interactive systems for crisis management will be introduced by describing background and related work. Following this, characteristics of medical device design related to crisis and disaster management are outlined. These sections are based on systematic literature review and experiences from previous research in the fields of pre-hospital and clinical care (cf. Mentler and Herczeg, 2014; Mentler et al.; 2016) as well as safety-critical human-machine interaction in general (cf. Mentler, Reuter and Geisler, 2016). Subsequently, these recommendations are applied to the domain of disaster and crisis management. Conclusions will be drawn and reflected upon in the last section.

BACKGROUND AND RELATED WORK

In the following sections, basic principles and process model of *usability engineering* covering "*concepts and techniques for planning, achieving, and verifying objectives for system usability"* (Beyer and Holtzblatt, 1998) are described. Afterwards, engineering approaches to crisis and disaster management systems resulting from systematic literature review in ISCRAM Digital Library are summarized.

Fundamental Principles and Process Model of Usability Engineering

Usability engineering, as a concept integrating several measures for ensuring and improving usability of interactive systems, can be traced back to the mid-1980s. Good et al. (1986) defined *usability engineering* as *"a process, grounded in classical engineering, which amounts to specifying, quantitatively and in advance, what characteristics and in what amounts the final product to be engineered is to have"*. According to them, usability engineering processes are characterized by

- defined metrics and levels of usability,
- design solutions analyzed with respect to meeting project goals,
- user feedback incorporated into an iterative design process.

These requirements and the analyze-design-build-evaluate-cycle (see Figure 1) provide the basis for standard like ISO 9241-210 describing the "*human-centred design for interactive systems"* and have been implemented in more sophisticated process models like *Contextual Design* (Beyer and Holtzblatt, 1998), *Scenario-Based Design* (Rosson and Carroll, 2002) or the *Usability Engineering Lifecycle* (Mayhew, 1999).

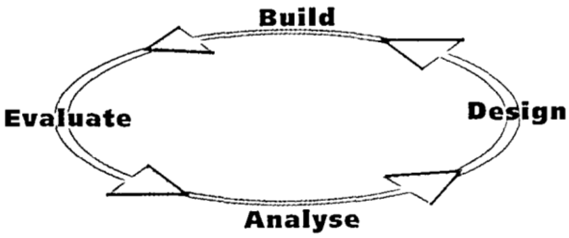

Figure 1. Usability Engineering Paradigm (Butler, 1996)

Both the ISO 9241-210:2010 standard and the previously mentioned design approaches are devoted to interactive systems in general and not particularly to safety-critical ones. For example, ISO 9241-210:2010 *"does [not] address health or safety aspects in detail"*. Rosson and Carroll (2002) state that *"safety has remained a side issue in usability engineering"* and outline how usability engineering techniques could be used to incorporate safety-related aspects. For example, they suggest to represent critical incident reports as scenarios in terms of *"[stories] about people carrying out an activity"* (Rosson and Carroll, 2002).

In any case, usability engineering for safety-critical contexts like crisis and disaster management has to be conducted in due considerations of challenges like extraordinary operational conditions (e.g. heavy rain, time-pressure), dynamic changes of mission parameters (e.g. number of casualties, affected areas) as well as users under high cognitive and physical workload. Apart from this, *"even early prototypes might require advanced levels of hardware and software quality"* (Mentler et al., in press). Therefore, methods from other engineering disciplines (e.g. software engineering, safety engineering) need to be incorporated in user-centered design approaches.

Engineering Approaches to Crisis and Disaster Management Systems

Over the last 20 years, research and development of interactive systems for crisis and disaster management have been increased. A systematic literature review of contributions to ISCRAM Digital Library should give an answer to the question which specific engineering approaches have already been applied by ISCRAM-related research groups to the development of crisis and disaster management systems. Subsequently, its results are summarized.

In January 2017, a *main field search* was conducted in ISCRAM Digital Library (http://idl.iscram.org/) considering data fields for author, title, publication (in terms of proceedings), keywords, abstract, area and conference. *Search terms* were "usability" (23 results), "engineering" (56 results), "usability engineering" (1 result), "user-centered design" (5 results), "user-centred design" (0 results), "human-centered design" (3 results), and "human-centred design" (0 results).

With respect to engineering in general, various approaches could be identified:

- *business process reengineering* (e.g. Charles et al., 2009; Hofmann et al., 2015) *"reevaluating existing internal norms and behaviors before designing a new system. This new evaluation process will address customers, operational efficiencies, and cost"* (Langer, 2016). For example, Charles et al. (2009) applied enterprise modelling approaches and tools to characteristics of humanitarian aid work. In this regards, *business process modelling techniques* have been used by several researchers (e.g. Barthe, Lauras and Benaben, 2011; Ooms and Van Den Heuvel, 2014).
- *resilience engineering* (e.g. Filho et al., 2014; De França et al., 2014) looking *"for ways to enhance the ability of organisations to create processes that are robust yet flexible, to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures"* (Dekker et al., 2008). For example, Filho et al. (2014) analyzed how a command and control center coped with unexpected events (especially large-scale protests) during a major sports event in Brazil.
- *requirements engineering* (e.g. Campbell et al., 2005; Groner and Jennings, 2012) in terms of *"the subset of systems engineering concerned with discovering, developing, tracing, analyzing, qualifying, communicating and managing requirements that define the system at successive levels of abstraction"* (Hull et al., 2011). For example, Campbell et al. (2005) conducted an empirical study in order to investigate how group and task structures affect quality of distributed and asynchronous requirements elicitation.
- *safety engineering* (e.g. Ristvej et al., 2010; Sharpanskykh, 2012) assuring *"adequate safety in advance of the deployment of a system"* (McDermid et al., 2009). For example, Sharpanskykh (2012) proposed a formal method to linking local actors and global characteristics in safety-critical organizations. In this regard, *risk management* in terms of systematic approaches to analyzing, assessing, controlling and monitoring risks is considered by several research groups (e.g. Eckle et al., 2016).
- *software engineering* (e.g. Diirr and Borges, 2013; Glantz, 2014) *"concerned with developing and maintaining software systems that behave reliably and efficiently, are affordable to develop and maintain, and satisfy all the requirements that customers have defined for them"*(ACM, 2006). For example, Diirr and Borges (2013) applied test and quality assurance methods (Formal Technical Review, mutation testing) to emergency plans for response teams.

It is worth mentioning that all of these engineering approaches overlap with user-centered process models to a certain degree but have different priorities and overall aims (e.g. not focussing on users' need in the first place). According to usability engineering, user-centered or human-centered design, most contributions to ISCRAM focus on one stage of the analyze-design-build-evaluate-cycle (see Figure 1). For example,

- Catarci et al. (2010) described the *usability evaluation methodology* applied during the development of a process management and geo collaboration system for disaster response forces. Their approach comprised controlled experiments, cooperative evaluations with domain experts, tests with external users not familiar with the domain and set-ups of concrete and realistic scenarios ("showcases").
- Mentler and Herczeg (2013) explained *interface and interaction design* of a tablet-based application for Emergency Medical Services (EMS) dealing with mass casualty incidents (MCIs). They applied the seven design principles of ISO-standard 9241-110 (e.g. suitability for the task, self-descriptiveness) to a mobile and safety-critical context of use considering challenges of designing an application which should to be suitable for users in both regular day-to-day services as well as rare missions with dozens or hundreds of casualties.

Only a few contributions have been devoted to overall usability engineering process models or applied techniques to different stages of development:

- Fischer and Klompmaker (2012) designed an interactive table to support rescue workers. They followed a *user-centered system design approach* and conducted contextual analysis, specified user requirements, designed a prototype, conducted a *"first evaluation"* with domain experts and presented further scenarios.
- Kluckner et al. (2014) summarized the development and evaluation of a graphical user interface *"of a simulation tool in crisis management"* following a *user-centered system design approach*. They referred to context analysis, requirements specification, prototype design and usability tests.

Context analysis, prototype design, usability tests and other usability engineering measures are essential for ensuring safe and efficient usage of interactive systems. As mentioned before, looking for approaches and methods incorporating safety-related aspects in more detail seems to be advisable.

USABILITY ENGINEERING FOR MEDICAL DEVICES

Crisis and disaster management is not the only and not the first safety-critical domain increasingly characterized by interactive systems (e.g. aviation, dispatch centers, healthcare, power supply, transport and logistics). However, knowledge transfer from one domain to another is challenging due to specific characteristics of different contexts of use.

In the following sections, it is explained whether and why standards and guidelines for usability engineering of medical devices should be considered for further improvement of crisis and disaster management systems. Afterwards, fundamental principles of the standards IEC 62366-1:2015 ("Application of usability engineering to medical devices") and ISO 14971:2007 ("Application of risk management to medical devices") are summarized.

Characteristics of Medical Device Design related to Crisis and Disaster Management

The context of use for medical devices bears resemblances to the one for interactive systems in crisis and disaster management with respect to the following aspects:

- diversity of users,
- diversity of devices and applications,
- diversity of operational conditions.

IEC 62366-1:2015 states that *"there can be a wide diversity of such individuals for any particular medical device including: installers, engineers, technicians, clinicians, patients, care givers, cleaners, sales, marketing"*. While some systems and applications (e.g. artificial respiratory equipment) might be used by trained professionals of single or several disciplines only, others might be available for both domain experts and laypeople. These characteristics can be compared to crisis and disaster management requiring

- computer-supported cooperation between professionals of single or several public service authorities and emergency services,
- computer-supported cooperation between professionals and volunteers ("emergent groups").

With respect to *technology*, medical devices range from wearable computing (e.g. smartglasses for surgeons; Mentler et al., 2016) to large-scale devices (e.g. magnetic resonance imaging system). Information systems, decision support systems and training systems are important *applications* (e.g. clinical information systems, electronic health records, simulations; Dahl et al., 2009; Shneiderman, 2011). Some of them might not be usable or not allowed to be used without prior instruction, others, e.g. automated external defibrillators, have to be regarded as *"walk-up-and-use products"* (Bevan and Raistrick, 2011). These classes of devices and applications are relevant to crisis and disaster management as well (Eckle et al., 2016; Parush et al., 2016).

The *diversity of operational conditions* for medical devices is indicated in Figure 2. From temporary installations in the field at night and during snowfall to well-equipped operation rooms with carefully adjusted lighting, heating and workplaces, medical devices must be usable (nearly) anywhere and anytime. The same can be determined in crisis and disaster management. Control rooms, on-site command vehicles, office environments, gathering places or outdoor environments are just a few possible working environments.

Figure 2: Exemplary environments for usage of medical devices

Finally, medical devices need to be applied in many crisis and disaster scenarios (e.g. mass casualty incidents after earthquakes; Garcia-Aristizabal et al., 2015). Nevertheless, their management might impose further challenges not present in medical device design and usage, e.g. long-lasting and spatially extended missions involving several actors at different locations for weeks, months or years. *Scalability*, in terms of the *"ability of a system to accommodate an increasing number of elements or objects, to process growing volumes of work gracefully, and/or to be susceptible to enlargement"* (Bondi, 2000), is a major challenge in developing crisis and disaster management systems affecting their usability as well. The same holds true for *interoperability* in terms of *"accessing relevant data at any time and sharing it across any levels of activities and parties involved in [Humanitarian Crises]"* (Shamoug and Juric, 2011).

Because of the outlined resemblances according to diversity of users, devices and operational conditions, guidelines and standards for medical device design should be considered, if dealing with usability engineering for crisis and disaster management systems. However, because of the outlined differences (e.g. scalability, interoperability) between these contexts of use, this should be done in a careful way.

Fundamental principles of IEC 62366-1:2015 and ISO 14971:2007

While ISO 9241-210:2010 refers to computer-based interactive systems in general (ranging from web sites to process control systems), IEC 62366-1:2015 and ISO 14971:2007 are domain-specific standards taking characteristics of medical devices and their usage into account. They specify

- normal and abnormal use,
- requirements for documenting usability engineering measures (usability engineering file),
- relationship between usability engineering and risk management processes.

Figure 3 shows the relationship between *normal and abnormal use* of a medical device according to IEC 62366-2015. It is worth mentioning that manufactures are only required to *"assess and mitigate risks associated with correct use and use error [...]"* (IEC 62366-2015). Abnormal use of a user interface (e.g. criminal offenses, reckless behavior) is out of the manufacturer's scope of responsibility.

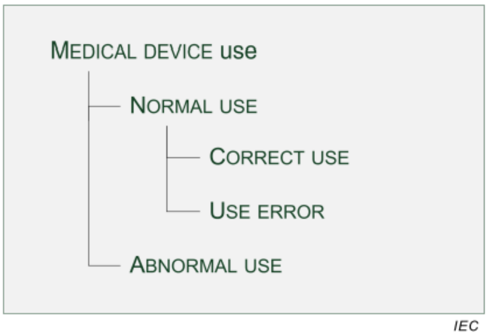

Figure 3: Relationship between normal and abnormal use (IEC 62366:1-2015)

However, manufacturers have to deal with possible use errors which could be caused by perception errors (e.g. failing to recognize a visual element), cognition errors (e.g. applying a wrong measure) or action errors (e.g. pressing a wrong button).

Actions to prevent use errors (e.g. formative and summative evaluations) as well as other measures have to be documented. IEC 62366-2015 states that all *"the results of the usability engineering process shall be stored in the usability engineering file"*. The Food and Drug Administration (2016) recommends a structure for such a usability engineering report. Among others, it should contain:

- descriptions of indented users, use, environments, training and user interface design;
- a summary of known problems with the user interface;
- a hazard and risk analysis;
- a summary of evaluations and details of human factors validation testing.

Relationship and interactions between usability engineering and risk management are described in IEC 62366-1:2015 with reference to ISO 14971:2007 in great detail. In this regard,

- risk management is a *"decision-making process for determining acceptable risk"* (IEC 62366-1:2015) and involves risk analysis, risk evaluation and risk control (ISO 14971:2007);
- usability engineering is a *"design and development process for the user interface to reduce the possibility of use errors that could result in risks associated with usability"* (IEC 62366-1:2015).

It is worth mentioning that this second definition is narrower than other ones in usability engineering and human-computer interaction: it embraces work reengineering and is not limited to user interface and interaction design (e.g. Mayhew, 1999). Introducing new or modified tools in a working environment affects the way users can solve their tasks. That's why procedures and workflows might have to be adjusted but this aspect is not covered in this standard.

Information flows between risk management and usability engineering process involve use specifications, safety-related user interface characteristics, known or foreseeable hazardous situations (e.g. from experience with a previous version), hazard-related scenarios describing use scenarios that could lead to a harm (IEC 62366-1:2015) and results of formative and summative evaluation measures.

USABILITY ENGINEERING RECOMMENDATIONS FOR CRISIS AND DISASTER MANAGEMENT SYSTEMS

In the following sections, recommendations for applying usability engineering measures to crisis and disaster management are derived from the previously described fundamental principles of IEC 62366-1:2015 and ISO 14971:2007. They refer to normal and abnormal use, usability engineering files and the relationship between usability engineering and risk management.

Normal and Abnormal Use

Because crisis and disaster scenarios can vary in many regards (e.g. damages, duration, dynamics, hazards, severity), utility and usability of a specific crisis and disaster management systems can hardly be predicted or even assured in general. While laboratory studies allow for control of many influencing factors, various stressors and influences can not be created intentionally. On the other hand, field studies require a lot of resources (e.g. observers, test devices, access to safety-critical areas) and can only provide insights for certain specific circumstances. Therefore, manufactures (e.g. software developers or usability engineers in research groups) should specify the intended use of their applications.

Defining a normal use would require to deal with potential use errors, too. Therefore, improved design solutions for error control, error correction and error management as means for error tolerance of interactive systems would be necessary and support users under high cognitive and physical load.

Abnormal uses in terms of intentional acts or omissions might be hard to prevent but manufacturers could try to describe under which circumstances their applications might not be usable in the intended way. Addressing system boundaries explicitly could be both a starting point for improvements and a facility to better match users', designers' and systems' mental model (Herczeg, 2014).

Usability Engineering File

Documenting essential characteristics of the context of use (intended users, use, environments, training and user interface design principles) as well as evaluation results should be mandatory for crisis and disaster management systems because it would ease third-party audits from usability experts and support accident analysis with respect to interaction problems.

Furthermore, it could guide both manufacturers (e.g. software developers or usability engineers in research groups) and domain experts not familiar with usability engineering measures in great detail. As stated by Mentler and Herczeg (2014): *"Managers and decision makers of [Emergency Medical Services] EMS providers often have a professional medical background but are not human factors and ergonomics experts"*. Comprehensive usability engineering reports could become an alternative means of understanding.

Usability Engineering and Risk Management

Dealing with known or foreseeable hazardous situations as well as describing hazard-related scenarios could improve usability of crisis and disaster management systems because these measures would require designers and developers to deal with "Doyle's Catch" (Alderson and Doyle, 2010): *"Computer-based simulation and rapid prototyping tools are now broadly available and powerful enough that it is relatively easy to demonstrate almost anything, provided that conditions are made sufficiently idealized"*.

However, crisis and disaster management offer conditions far away from being ideal for computer-based interactive solutions. Time- and safety-critical circumstances put high requirements on users, technology and their interaction respectively cooperation. Therefore, usability engineering and risk management processes should be aligned in order to ensure safe and efficient human-computer interaction even under extraordinary circumstances. Techniques of resilience and safety engineering (see the previous section) could be a valuable addition helping a system to become *"SURE (Safe, Usable, Reliable, and Evolvable)"* (Palanque et al., 2007).

CONCLUSION

Systematic development of crisis and disaster management systems is both crucial and challenging. As a systematic literature review reveals, several engineering approaches have been used by ISCRAM-related research groups. *Business process reengineering* and *business process modelling techniques*, *resilience engineering*, *requirements engineering*, *safety engineering* and *risk management measures*, *software engineering* and *usability engineering* overlap to a certain degree but have different priorities and overall aims. Usability is is a crucial factor for suitability of interactive system in crisis and disaster management. Usability engineering measures are essential for ensuring safe and efficient usage. In order to incorporate safety-related aspects more carefully, approaches and methods from other safety-critical domains should be considered. Because the context of use for medical devices bears resemblances with respect to diversity of users, diversity of devices and diversity of operational conditions, fundamental principles of domain-specific standards and guidelines should be considered. Because there are differences (e.g. scalability, interoperability) between these contexts of use, this should be done in a careful way. Concepts like the distinction between normal and abnormal use, usability engineering files and risk management incorporation could be valuable complements to commonly used general or user-centered engineering approaches in crisis and disaster management. Nevertheless, further research is necessary on knowledge transfer between safety-critical domains. Finally, formative and summative evaluations of prototypes developed according to the mentioned concept have to be conducted in order to demonstrate their importance.

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Quality Improvement of Remotely Volunteered Geographic Information via Country-Specific Mapping Instructions

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ABSTRACT

Volunteered geographic information can be seen as valuable data for various applications such as within disaster management. OpenStreetMap data, for example, are mainly contributed by remote mappers based on satellite imagery and have increasingly been implemented in response actions to various disasters. Yet, the quality often depends on the local and country-specific knowledge of the mappers, which is required for performing the mapping task. Hence, the question is raised whether there is a possibility to train remote mappers with country-specific mapping instructions in order to improve the quality of OpenStreetMap data. An experiment is conducted with Geography students to evaluate the effect of additional material that is provided in wiki format. Furthermore, a questionnaire is applied to collect participants' socio-demographic information, mapping experience and feedback about the material. This pre-study gives hints for future designs of country-specific mapping instructions as well as the experiment design itself.

Keywords

OpenStreetMap, country-specific mapping instructions, VGI, quality, disaster.

INTRODUCTION

The number of people affected and the damage produced by natural hazards, like floods, are increasing in the last decades (EM-DAT, 2016). This can be mainly attributed to changing climate conditions, the urban expansion in risk areas due to a rapidly-growing world population and the impact of human beings in nature (Ebert et al., 2009). Thus, disaster management plays an important role in dealing with such events. However, oftentimes, official data, e.g., map material for routing or the location of buildings, is not available or out of date. Therefore, in order to react in an efficient and fast way, there is already a high number of cases, in which volunteered geographic information (VGI) is used within natural hazard analysis (Horita et al., 2015; Klonner et al., 2016).

The map project OpenStreetMap (OSM) can be considered as very useful for such applications and since its first crisis setting in 2010 after the earthquake in Haiti, OSM has been applied for many use cases (Soden et al., 2014b). Further, the Humanitarian OSM Team (HOT), which evolved from the Haiti earthquake response, develops mapping tasks in cooperation with humanitarian aid organizations. In addition, projects like Missing Maps[1] bring forward the need of map material for preparedness in order to have current map data already available before a disaster occurs. However, the quality has to be evaluated before data of a collaborative project like OSM, which is collected, edited and shared by volunteers from all over the world, can be applied in disaster management (Barron et al., 2014; Fan et al., 2014). This is especially important for crisis maps because most of the mappers work remotely on the basis of satellite imagery, and therefore, they might neither be familiar with the local conditions nor have country-specific (geographic) knowledge (Eckle et al., 2015).

An experiment conducted by Eckle et al. (2015) tackled this issue and they compared remotely mapped data by Geography students to the results of a local mapper from Kathmandu. They focused on Kathmandu in Nepal because this area is earthquake prone and the local Kathmandu Living Labs team[2] supports the mapping of the area in OSM since official data is very sparse (Soden et al., 2014a). The experiment of Eckle et al. (2015) can be considered as an initial study as it only had eight participants for the remote mapping. They state that their methods should be tested with a larger sample size and that the results showed that errors made by the remote mappers could be minimized by providing material explaining country-specific features. Moreover, See et al. (2013) portrayed in their study that with specific training and individual feedback, volunteers were able to improve more than experts of the domain.

Therefore, the objective of the following study is the quality analysis of remote mapping and the evaluation of the effect of additional material about country-specific features with a larger experiment setting, which is based on the Solomon Design and 72 Geography students as participants. A wiki page provides the additional country-specific instructions for the remote mapping and the experiment concludes with a questionnaire. The analysis of the results is based on correctness and completeness via a comparison of data contributions by the students versus OSM reference data.

STUDY AREA AND DATASETS

In general, during or after a disaster, remote mapping data is contributed to OSM mainly in areas, where no or only little map material is available from the official side. Therefore, there is generally a lack of independent reference data in order to evaluate the mapping quality of the volunteers.

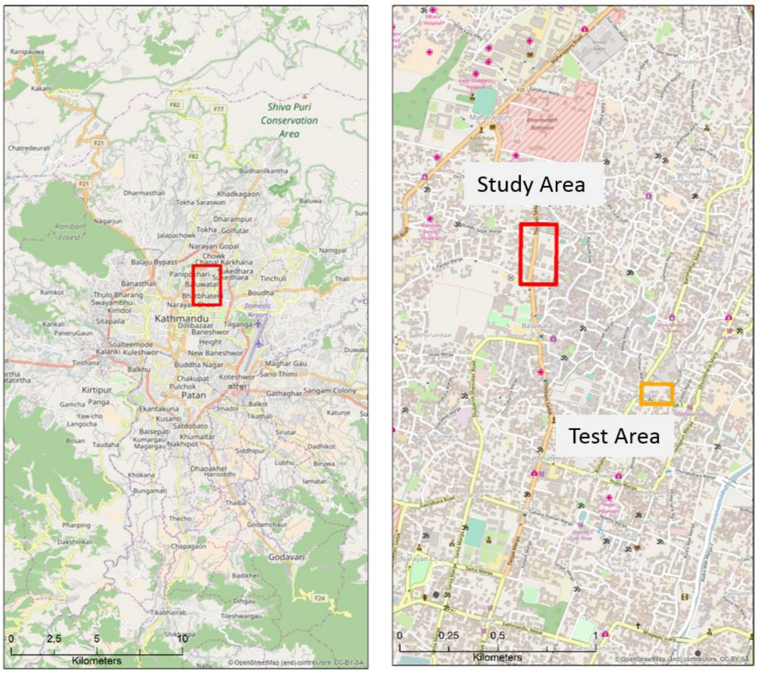

Figure 1. Study area in Kathmandu, Nepal.

The research area of the following quality examination is located in the city centre of Kathmandu, Nepal, (Figure 1) due to the following advantages in comparison to other remotely mapped areas. In 2012, a project aiming at the seismic resilience of the Kathmandu Valley was launched by the World Bank, the Global Facility for Disaster

[1] http://www.missingmaps.org/ (accessed: 15.01.2017)

[2] http://www.kathmandulivinglabs.org/ (accessed: 14.01.2017)

Reduction and Recovery (GFDRR) and the Government of Nepal[3] (Soden et al., 2014a). There was no complete database of schools and health facilities combined with coordinates and information about construction type available for a disaster risk model (ibid.). The collection of these data by locals within the Open Cities Kathmandu project was taken over after the end of the project by the Nepalese NGO Kathmandu Living Lab (ibid.). These efforts led to a rich OSM database, which is constantly updated. Moreover, during and after the earthquake in Nepal 2015, OSM was updated by thousands of remote and local mappers, including many experienced ones. This suggests high data quality and the OSM data are therefore used as a reference for the evaluation of the experiment data. To avoid any influence due to new satellite imagery, the reference is downloaded from the OSM data base on the day of the experiment (15.12.2015). The students' mapping data is based on the same Bing satellite imagery and for their mapping they use JOSM[4], a Java based open source editor for OSM. In addition, Kathmandu is chosen as research area following the previous experiment conducted by Eckle et al. (2015), in order to have comparable conditions.

METHODOLOGY

Experiment Design

An experiment can be seen as a form of an empirical study, which aims at identifying cause-effect-relations in order to explain social phenomena (Eifler, 2014). Processes are actively evoked by the experiment leader to identify the real cause of a phenomenon and therefore it is important to control factors that could also be causes to avoid alternative explanations (ibid.).

Further, Eifler (2014) states that a control group makes it possible to control the factors which influence the internal validity and that specific controlling techniques can be applied such as eliminating disruptive elements or keeping them constant as well as selecting the group randomly or parallel. In accordance, the Solomon Four Group Design is used as it aims at avoiding the influence of a pre-test, which is the mapping of a testing area in the following study, on the mapping results of the post-test, i.e. the mapping of the study area in the experiment. Since this method allows to exclude influences on the internal validity (ibid), it is chosen for conducting the experiment.

Participants

A Cartography lecture of 90 minutes was chosen as experiment setting and 72 students, mostly in their first semester, were taking part. It was assumed that these students represent to a certain extent the mapping community of new users. Moreover, this setting allows to have a similar set of participants regarding age and education and to have enough participants in order to provide about 20 participants per group. As Geography is a subject usually with quite equal gender distribution, the final group of participants consists of 36 female and 36 male students.

Tasks

All participants were attending the same introductory session with information about the experiment itself and explanations about the tools the students were going to use for the mapping (JOSM editor). Afterwards, they were randomly distributed into four different groups (Figure 2). Due to practical reasons and the setting, the distribution was not completely random in the experiment described here, but it was intended to make it as randomly as possible by handing out the same amount of task sheets for each group to the students. The task sheet included specific instructions about what to map and whether to read an additional wiki page (link was provided on the sheet). Each task on the sheet was assigned with a certain amount of time for fulfilling. The instructors of the experiment also reminded the participants of the single groups about the time. Moreover, the test area as well as the study area outline was provided on an online learning platform for the download into JOSM, which allowed the students to easily identify the area of mapping in the satellite image. After the mapping part, the students had to upload their results to the online platform. The task sheet gave further information about the folders on the online learning platform and the way they should save their data. The last task for all group participants was the questionnaire, for which a link was provided on the sheets.

Half of the participants had to do a pre-test, the test area in the experiment. One part (group 1) had to read the additional material on the wiki page first, before starting mapping the test area. They got a certain amount of time to do that. Group 2 could directly start with the test area. After mapping the test area for 10 minutes, both groups started the post-test, the study area in our experiment. The other half of the participants had no pre-test and again

[3] http://www.opencitiesproject.org/cities/kathmandu/ (accessed: 19.01.2017)

[4] https://josm.openstreetmap.de/ (accessed: 19.01.2017)

one group had additional material (group 3) in contrast to the control group (group 4). These two groups only mapped the post-test (study area).

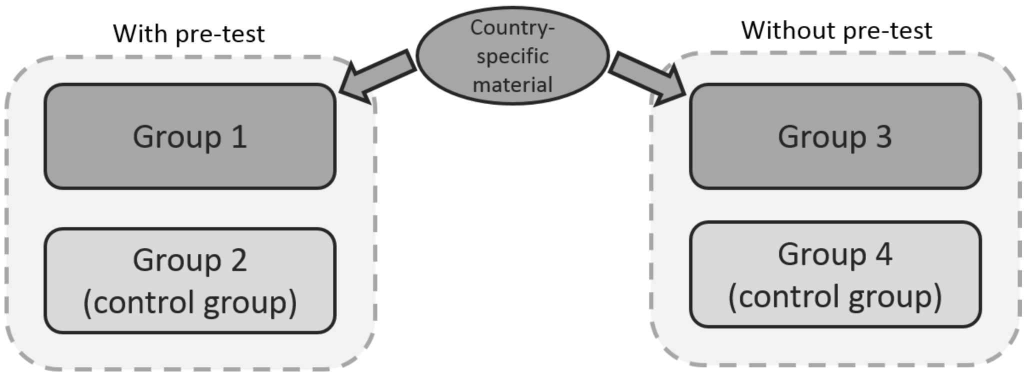

Figure 2. Experiment design based on the Solomon Four Group Design.

Wiki Page

The form of a wiki page is used for the experiment as, especially within educational contexts, this method proved to be a successful way for collaborative knowledge building (Kump et al., 2013). Cultural specific information for remote mappers can be provided and the content is based on experience and local knowledge of many people. Thus, a wiki enables, for example, the large OSM community in general, or the crisis mappers in specific, to contribute and share their local knowledge about a certain area with remote mappers. In urgent disaster cases a specific use case wiki page can be added. Moreover, it is possible, to share the information in different languages. Some of the content of the applied wiki page for the experiment was already in use after the earthquake in Nepal in 2015 and proved to be useful for remote mapping. This shows both the importance and applicability of such methods but also the urgent need to evaluate these tools in order to make statements about the quality of the resulting mapping and the possibilities of improving the portrayal of additional material.

The wiki of the experiment[5] comprises of characteristics of buildings of this region with specific mapping hints. It considers buildings that are irregular in elevation and therefore might appear as a set of houses, a row of houses, which may look like one big house, and complex building structures like multi-polygons (Figure 3). Further, the correct mapping of the actual layout of a building is explained. Focus is set on buildings as they are mostly the features new mappers start with. Moreover, especially for disaster management, the exact outline and the number of buildings is important for population estimation or to identify the type of usage of the building, e.g., elements at risk like schools or hospitals have often a certain shape.

Figure 3. Wiki page with additional information about specific features. Example of multi-polygon creation[6].

[5] https://wiki.openstreetmap.org/wiki/Nepal_remote_mapping_guide_Experiment (accessed: 15.01.2017)

[6] Ibid.

Questionnaire

The experiment consists of a mapping part followed by a questionnaire in order to gain background information about the students such as their age, gender, semester, and experience with geoinformation, remote mapping and OSM. Another issue is their knowledge about Kathmandu. Additionally, information about the mapping material and the applicability is inquired. Furthermore, they are asked about the time for finishing the task and the language issues. Finally, the motivation of the students for further mapping is evaluated. A link for the questionnaire is included in the task sheet.

Analysis

The overall hypothesis of the experiment is that additional country-specific mapping instructions improve the mapping quality of remote mappers. Therefore, the following section presents analysis methods to measure the quality of the data mapped by the students in comparison to the OSM reference data.

Different indicators can be used in order to evaluate the data created by the students. The ISO standards 19157:2013 (International Organization for Standardization) provide a set of quality indicators for geographic information, which are also described in the work of van Oort (2006) and Haklay (2010). The ISO standards define correctness or positional accuracy as “the accuracy of the position of features within a spatial reference system”, while completeness is referred to as “the presence and absence of features, their attributes and relationships” (ISO 19157:2013). In the context of this analysis, the correctness indicates the accuracy of the mapped features by the students, whereas completeness reveals excess and missing data in the student dataset (cf. Rutzinger et al., 2009). Therefore, the indicators of correctness and completeness can be used to evaluate the quality of the mapping results of the students.

Klonner et al. (2015) applied two comparative methods for the work with OSM data in urban areas, namely the centroid and the overlap method. They conclude that the overlap method achieves more realistic results in areas with terraced houses and blocks of buildings. The urban area of Kathmandu resembles this kind of building structures, and therefore this method is chosen for the study at hand and applied for the comparison of the students’ mapping results to the reference OSM data. Figure 4 shows an example of a mapped building within the student data (orange outline) and the reference data (red outline) as well as the area of their intersection. This intersection of the two building polygons represents the overlapping area (Klonner et al., 2015). Thus, in other words, the overlapping area shows the correctly mapped student data. In the example (Figure 4), the overlapping area (light orange) covers the entire reference building, which indicates that the student even overestimated the building area.

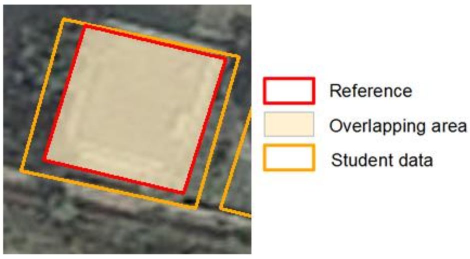

Figure 4. Example of a building in the reference data and mapped by a student. The overlapping area can be used for a comparison.

The overlapping area of the houses of the two datasets can be compared to the overall area of the building polygons mapped by the students and, of the reference buildings. These calculations can be used to assess the quality indicators. The completeness refers to the ratio of the overlapping area of all buildings and the sum of all areas of the buildings in the reference data. Correctness stands for the ratio of the overlapping area of all buildings and the area mapped by the students (cf. Rutzinger et al., 2009).

completeness = overlapping area of all buildings/ area of buildings in the reference data.

correctness = overlapping area of all buildings/ area mapped by the students.

RESULTS

In the following, the results of the mapping by the students during the experiment are evaluated based on the indicators of completeness and correctness. Moreover, the outcomes of the specific tasks such as the mapping of a multi-polygon and a row of houses are presented. The final part gives further information provided by the students within the questionnaire.

Mapping

The calculations of completeness and correctness can be done for the whole study area as well as for the test area. In this way percentages for all student datasets can be evaluated. The following section shows the results of a qualitative analysis due to the available sample size. The final number of student submissions (69) differs from the participant number (72) because three of the student datasets had to be excluded due to invalid data.

Figure 5 shows an example of a student of group 1. The map shows the study area with the reference building area (red outline), building polygons mapped by the student (orange outline) and the overlapping area (light orange area). This student resulted in a mapping completeness of 86% and correctness of 62%.

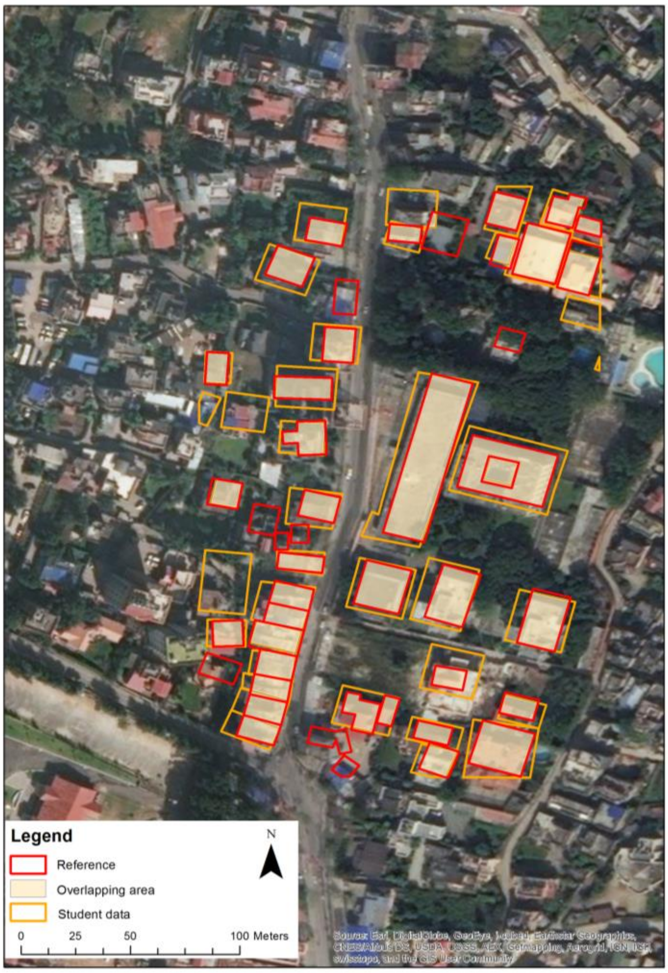

Figure 5. Buildings in the reference data (red) and mapped by a student (orange) as well as the overlapping area (light orange) in the study area of Kathmandu, Nepal.

The sample size of each group ranges from 16 to 18 participants and thus the following statistical analyses are not representative but can give some insights for further experiment designs. First of all, the average correctness values from group 1 and group 3 are compared in order to see whether there is an influence of the test area. A corresponding t-test results in a non-significant outcome ($p = 0.84$). The same comparison for the completeness results in a p-value of 0.53, and is therefore also not significant. So, it can be assumed that there is no influence of the test area, which allows future experiments to have only 2 groups instead of the 4 groups, which enables larger sample sizes of the groups for representative evaluations.

The assessment of the impact of additional information is based on the analysis of the country-specific features portrayed in the wiki and how the students succeeded in their mapping. In the following, focus is set on the mapping of a multi-polygon and a row-of-houses. The results of these analyses can give hints for the improvement of the wiki page for the follow-up experiment with only 2 groups and a larger sample size.

Moreover, the feature of the multi-polygon (Figure 6) can be used as an indicator whether the students really used the additional material. In the experiment of Eckle et al. (2015) it was not identifiable whether the participants read the material or mapped without reading it. This addition of the multi-polygon makes this possible as new mapper usually do not apply such specific features.

Table 1. Multi-polygon

	Group 1	Group 2	Group 3	Group 4
Use of multi-polygon	14 of 18 (78%)	1 of 18 (6%)	9 of 16 (56%)	2 of 17 (12%)

Figure 6. Example of a multi-polygon mapped by a student of group 1 (left) and not mapped by a student of group 2 (right).

The results show that the students of group 1 and group 3 read the material and used the multi-polygon in contrast to only a small number of mapped multi-polygons in the groups without the additional material (Table 1).

Table 2. Row of houses

	Group 1	Group 2	Group 3	Group 4
row of houses as several single houses AND correctly mapped (7±1 and >80% completeness)	3	3	1	0
row of houses as several single houses BUT ≤80% of area of houses are overlapped (completeness) or/and not 7 (±1) polygons	8	13	11	15
row of houses mapped as 1 single building	4	0	2	2
row of houses not mapped	3	2	2	0

For the evaluation of the mapping of the row of houses, different categories have to be applied because there are several ways to map this specific feature (Table 2). Some students did not map the row of houses at all, while others made one single large building. For the students who mapped single buildings a threshold was applied: The row of houses was only counted as mapped correctly when the number of polygons was 7±1 (of the 7 reference polygons) and the completeness of this specific feature was >80% (Figure 7).

Figure 7. Mapping of a row of houses. From left to right: reference data with 7 single polygons, correctly mapped data by the student, several buildings mapped by student but under the threshold of completeness, only one large building mapped for the row of houses.

On the wiki, the instruction for a row of houses also includes the remark that if they are not sure, they should map it as one big building. The comparison of group 1 and 2 shows that the students might have followed this advice as 4 students of group 1 made one big building in comparison to no one in group 2.

The overall results of the mapping of a row of houses of all groups indicate that the correct mapping is still very difficult for beginners. This has to be taken into consideration when using OSM data for disaster management or other applications.

Questionnaire

Only one of the students had been in Kathmandu before the experiment. The results of this student (group 4) are above the average of all groups, which might be a hint to the usefulness of local knowledge.

Moreover, the questionnaire reveals that some students had problems regarding the language. While this is only true for 15%, this still might indicate that future material provided for crisis management by HOT, for example, might even lead to more accurate mapping results if it is translated in different languages, which is technically straightforward in a wiki.

Regarding the time the students had available for the mapping task, the questionnaire shows that 24 students had no time problem while 44 either had to hurry up to finish the task or had not enough time to finish it. 4 did not respond. This time issue is due to the experiment setting because in real mapping situations the students could take their time for mapping.

DISCUSSION AND CONCLUSION

The experiment can be seen as a first step towards the evaluation of the impact of additional country specific material provided for remote mappers. In this paper, only a small analysis is portrayed as the work is still in progress. An extensive analysis of the questionnaire and the mapping of the remaining specific features will also show the different mapping results with respect to the time constraints, to previous knowledge or how the students rate their improvement themselves due to the mapping material.

Additionally, this pre-study gives hints about the experiment design and that the follow-up experiment does not need to use the Solomon Design anymore. The evaluation shows that there is no significant influence of the test area. Thus, only 2 groups are necessary for another mapping experiment allowing for larger sample sizes.

Moreover, regarding the wiki page, this experiment also reveals valuable information for improvement of a future experiment setting as there are still some issues that need to be taken into consideration such as language barriers. Furthermore, on the one hand the mapping might have been influenced by the motivation as, although the experiment was a near-to reality mapping, the students still had a different motivation than normal OSM mappers. On the other hand, the tasks of the experiment did not clearly distinguish whether the overall aim is correct mapping (so no time constraints) or mapping as much as possible (with time pressure). In a follow up testing, the exact indication of the aim of the mapping, whether completeness or correctness is required, should be made clear at the beginning in order to have the same setting for all.

Future work may also include further quality measures in order to face the complexity of crisis mapping. Semantic accuracy, for example, plays an important role especially regarding critical infrastructure. It gives insights into the link between the (geometric) representation of an object and the intended interpretation. Moreover, temporal accuracy can provide information about updates of the dataset regarding changes in the real world (van Oort, 2006; Haklay, 2010).

As remotely contributed VGI is gaining more and more importance in the disaster management sector (Eckle et al., 2016; Horita et al., 2015; Klonner et al., 2016), there need to be tools for enhancing the mapping quality already during the production phase. The study reveals that students use such guides like the description of the mapping of multi-polygons. However, for more complex issues like the outline of a row of houses, there is no clear difference between mappers who used additional material and mappers without specific information. Therefore, it has to be kept in mind that remotely mapped OSM data is very useful for crisis mapping, but that it cannot give all the details local mappers can provide and which might also be required for efficient disaster management. This shows that it is important to select the mapper type (remote or local) according to the task, which has to be supported. In addition, the management of the input of such heterogeneous groups needs to be taken into consideration in future work. Further, it is also advisable to include local communities to the creation of more specific mapping instructions because it is necessary to find out the needs of local actors or specific use case requirements. In the experiment case, the material was already approved to be useful during the crisis mapping of the Nepal earthquake in 2015.

ACKNOWLEDGEMENTS

This work was supported by the WIN-Kolleg of the Heidelberg Academy of Sciences and Humanities (HAW). The authors would like to express gratitude to the students of the Cartography lecture for participating in the experiment. Special thanks to René Westerholt for his advice on the statistical evaluation.

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Behind the Scenes of Scenario-Based Training: Understanding Scenario Design and Requirements in High-Risk and Uncertain Environments

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ABSTRACT

Simulation exercises as a training tool for enhancing preparedness for emergency response are widely adopted in disaster management. This paper addresses current scenario design processes, proposes an alternative approach for simulation exercises and introduces a conceptual design of an adaptive scenario generator. Our work is based on a systematic literature review and observations made during TRIPLEX-2016 exercise in Farsund, Norway. The planning process and scenario selection of simulation exercises impact directly the effectiveness of intra- and interorganizational cooperation. However, collective learning goals are rarely addressed and most simulations are focused on institution-specific learning goals. Current scenario design processes are often inflexible and begin from scratch for each exercise. In our approach, we address both individual and collective learning goals and the demand to develop scenarios on different layers of organizational learning. Further, we propose a scenario generator that partly automates the scenario selection and adaptively responds to the exercise evolvement.

Keywords

Humanitarian simulation exercise, scenario design process, collective learning, interorganizational coordination.

INTRODUCTION

Requirements of scenario development are domain specific; whether it is disaster management (Meesters and Van de Walle, 2014), water management (Dong, 2013), or military training (Hartog, 2009). In addition, the planning of scenario-based training requires intensive domain knowledge and specific learning aims. It often lacks the agility to be re-used in creating new scenarios, or to be scalable in different environment (Luo, Yin, Cai, Lees, & Othman, 2014, Pharmer & Milham, 2016).

In the field of disaster management and humanitarian aid, response operations involve different levels of cooperation and coordination among numerous international and national organizations and authorities. Success and failure of missions is determined by many factors: the organizations' specialties and capacities, resources availability, and field conditions create an extremely dynamic and challenging environment for field coordination (Comfort & Kapucu, 2006). Coordination networks among humanitarian organizations (Noori & Weber, 2016) and coordination clusters among organizations engaged in emergency response operations (Noori, Wolbers, Boersma, Cardona, 2016) are in place to deal with the complexity of operational dynamics in disaster response. The network-based view provides a holistic and task oriented scope of the operational environment and identifies core elements of disaster and emergency operations in unstable environments.

Scenario-based methods present a valuable tool to improve the performance of decision-making in the field of disaster and emergency management. There is a wide variety of scenario approaches related to planning and policy-making (Amer, Daim & Jetter, 2013) that is mostly related to forecasting the future by constructing different possibilities within certain contexts (Kosow and Gaßner, 2008). Developing paths that enable the achievement of organizational or societal aims largely drives those goal-oriented approaches. However, the high levels of risk and uncertainty in response operations and the dynamic and volatile environment make the task of planning and selecting scenarios more difficult (Comes, Hiete, Wijngaards & Schultmann, 2011). Scenarios selection for exercises and simulations in the field of disaster response need to be purposeful and relevant in addressing specific learning aims (Comes, Wijngaards, Maule, Allen & Schultmann, 2012). Purposeful scenarios respect time and resource constraints, correspond to unfolding dynamics of events in real-time, and contain context and elements affecting the process of decision-making (Comes, Wijngaards & Van de Walle, 2015).

In many countries, civil defense and organizations involved in disaster and emergency response follow the formal and highly structured Incident Command Systems (ICS) in their training exercises and actual response operations (Boersma, Comfort, Groenendaal & Wolbers, 2014). ICS consists of a number of mandates and protocols describing communication and coordination between response organizations (Bigley & Roberts, 2001). However, studies based on network analysis found that members of response networks self-organize following tasks needed during response operations and do not necessarily follow the rigid ICS structure (Topper, C. M., & Carley, K. M. 1999; Noori, Wolbers, Boersma & Cardona, 2016). The emerging task-based structures proved flexibility and resilience in responding to uncertainty and dynamic changes during both natural and humanitarian disasters (Noori & Weber, 2016). Following ICS in their exercises and lack of scenario adaptability to dynamic condition in real-time; made it difficult for humanitarian and civil defense organizations to exploit the benefits of coordination-network behaviors to increase resilience and agility.

This paper focuses on scenario-based exercises that target humanitarian aid operations as parts of a larger effort aiming at the improvement of the security and the efficiency of humanitarian aid work. The work is based on observations made during TRIPLEX-2016 exercise, one of the largest exercises for humanitarian organizations. It is organized every three years by the International Humanitarian Partnership (IHP) with a focus on exercising cooperation and coordination among various organizations. It involves joint response planning by humanitarian organizations, civil protection authorities, and other entities.

This paper is structured as follows. The background section examines the importance of and requirements for scenario-based training, scenario design and requirements in disaster and emergency management context. The section of TRIPLEX-2016 case study provides details of the exercise itself, its scenario design process and implementation. In the following section, a framework for generating scenarios in unstable contexts is introduced. It is developed based on the literature and the observations made during TRIPLEX-2016 Finally, in the discussion and conclusion we reflect on the insights gained and outline room for future research.

RESEARCH METHOD AND DATA COLLECTION

The research strategy followed in this paper was twofold. First, a systematic literature review was conducted (Creswell, 2013) using combinations of the following key words: simulation exercise, scenario development, scenario design, and injects, collaborative response, interorganizational coordination, and humanitarian aid. The literature review objective was to compile literature about scenario development and simulation exercises mainly in disaster management and humanitarian aid and other related fields like healthcare and military. Second, a team of researchers joined the TRIPLEX-2016 exercise in Norway. During the preparation and execution phases, we conducted participant observations as a social science research method based on gathering data from personal experience made by observation and participating in activities and discussions (Musante & DeWalt, 2010).

BACKGROUND

Scenario-Based Training in Disaster and Emergency Management

Scenario-based training and simulation exercises are powerful tools that enable organizations to (1) train executing relevant procedures and processes; and (2) practice decision-making in complex and dynamic environments (Lateef, 2010; Comes, Wijngaards & Van de Walle, 2015). Exercises provide insights into the organization's, team and individual performance. On the organizational level, exercises enable assessing the implementation of concepts such as inter-organizational coordination, reveal shortcoming and gaps in planning, and improve organizational coordination. On team level, trainings can support the elimination of ambiguity by clarifying roles and responsibilities. Finally, for individuals, it can help to strengthen the confidence in operational roles and helps to gain recognition and support of official (Pharmer & Milham, 2016).

Simulation exercises can emulate ambiguous and equivocal situations that humanitarians face in their operations in the areas of armed conflicts and the aftermath of natural disasters. Besides, simulation-based learning can be applied in designing a learning experience aimed at practicing other objectives that are hard to address otherwise (Hartog, 2009; Nikolai, 2014). A simulated environment can represent the central characteristics of a dynamic and complex system in order to understand and experiment within this system (Duke, 1980). Participants take over certain roles within this system (Duke & Geurts, 2004). The scenario in this sense is the setting of the simulated environment to constrain behaviors and to simulate the complex system (Greenblat & Duke, 1975). The scenario or the simulated environment plays an important role as supporting means for (1) the experience, (2) the effectiveness and difficulty of the simulation, and (3) the feeling of flow or immersion of participants' experiences when doing the exercise (Lukosch, van Ruijven & Verbraeck, 2012).

For example, it is widely recognized that no single organization can undertake all aspects of disaster response alone but instead responses require to pool and allocate resources from many organizations, including affected government entities, UN agencies, international and domestic NGOs, and affected civilian populations (Kapucu, 2009; Kapucu, Arslan, Collins, 2010; Butts, Acton, Marcum, 2012; Noori & Weber, 2016). Figure 1 shows is an example of a response network of a humanitarian aid mission for refugees in a conflict zone. Despite the complexity in cross-organizational coordination, organizations are self-organized in the form of task-based clusters (marked with dotted circles in Figure 1): national relief sector, international relief sector, and logistics.

Therefore, scenarios simulating such complex environments require joint exercises as an effective way to build trust among actors, and deepen the knowledge and confidence in coordination concepts such as the cluster system. Further joint exercise approach supports and enhance mutual understanding of roles and mandates (Banuls, Turoff, Hiltz, 2013).

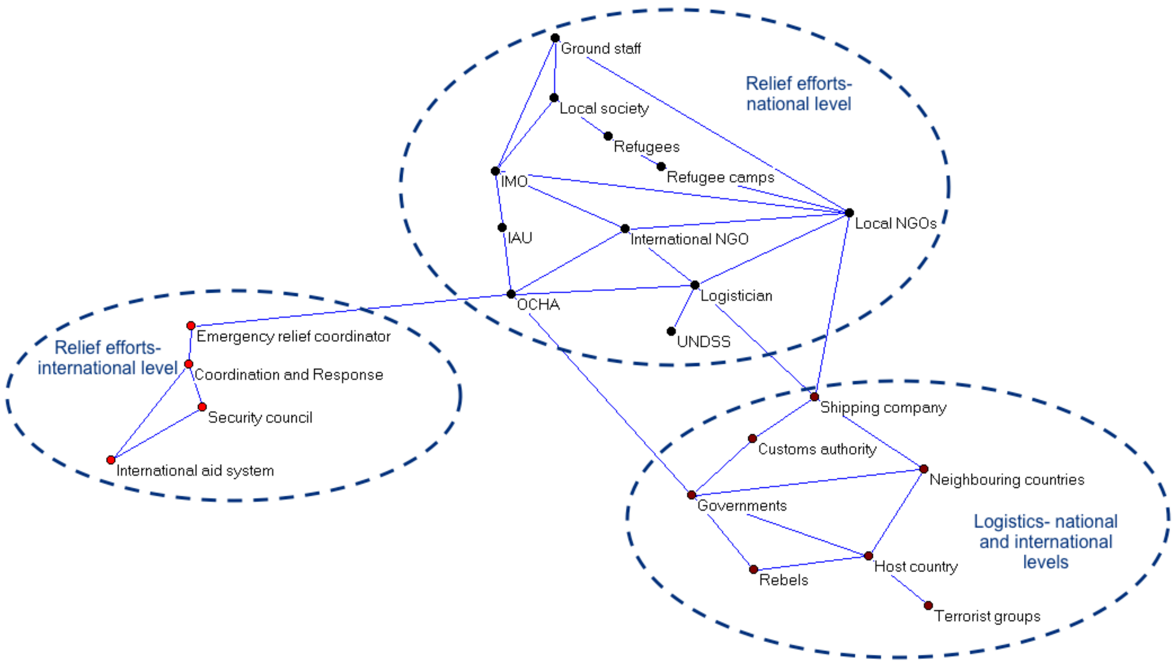

Figure 1. Coordination complexity for a humanitarian aid mission in conflict zones.

Scenario Development for simulation exercises

In essence, scenarios are stories on how the future could potentially evolve. Scenario development techniques aim to compile a comprehensive set of plausible clearly defined situations that can be tested (Wright & Goodwin 2009; Schoemaker, 1993). The multitude of scenarios relates to the uncertainty about the behavior of the system and the complexity and diversity of crisis response operations. Nevertheless, covering all possible scenarios is infeasible, as this would require an infinite number of scenarios or situations to be played (Comes et al. 2011). Hence, using scenarios entails explicit or implicit scenario management – meaning to balance scenario construction with limited time and resources.

Scenarios in simulation exercises aim to be challenging and test the response of professionals. The scenario design process fundamentally determines the effectiveness of the training. However, planning simulation exercises are known to be a complex and resource intensive process. Different approaches have been proposed to conduct the scenario design. Dong (2013) emphasizes that the scenario design procedure should be iterative and encompasses at least the following three steps. First, the main focal questions, driving forces and sources of uncertainty should be clearly written down. Second, the storyline should be formulated and the scenario logic be constructed. Finally, the scenarios should be linked to the goals and issues of interest.

Although appearing in a different wording, the use case modeling (Bittner and Spence, 2003) can also be considered as a scenario design process. For every use case, the roles of involved actors, their interactions and associations with each other and the environment are specified. Uses -cases are normally defined in a workshop setting and jointly it is decided about the relevance of the use case and the expected behavior in certain situations.

The US Department of Homeland Security Exercise and Evaluation Program (HSEEP) describes an inventory of all potential injects named Master Scenario Event List (MSEL) as key element in the successful planning of an exercise. The MSEL is the exercise blueprint, consisting of a structured listing of the injects, each of which contain a brief description of events, expected actions, intended players and estimated time of inject (Teclemariam & Yang, 2014). It is designed such that each inject is linked back to one or more exercise objectives and provide options for adaptive exercise play. Importantly, injects should be grounded in reality, so that players feel motivated to execute the policy or procedure being tested. Renger (2009) propose the following steps for writing the MESEL:

1. Delineate size and location of exercise
2. Formulate objectives of exercise
3. Define exercise events and add an initiation inject for each event
4. Write reminder inject (trigger response when inject is not taken up)
5. Brainstorm redirect injects (anticipate other plausible actions that may still resolve situation)
6. Include non-objective injects (optional and only used to fill time gaps)
7. Estimate times for each inject

Scenario-Based Training in Dynamic, Complex, Uncertain and High-Risk Environment

Simulation exercises and the described methods for scenario design have been adopted in a wide range of application fields from health care, civil protection, humanitarian, and the military. Despite the differences, all those fields share common work settings, which are described as dynamic, complex, uncertain and high-risk environments. In this paper we specifically study the process of planning and designing scenario-based exercises for disaster and emergency response operations.

Acknowledging the complexity and dynamics of the settings, it is important that the scenarios can adapt in real-time to the unfolding exercise. Enabled by modern monitoring and tracking technology, we understand a scenario no longer as a static playbook, but as a dynamic network of events (injects) and response by the players to ensure that training objectives will be achieved. In this sense, we propose to use approaches of scenario selection and relevance assessment (Comes et al., 2012) as a way to develop scenario paths in real-time.

Learning objectives are manifold; therefore we only focus on two common key issues:

Firstly, both scholars and professionals have referred to improving the level of collaboration among the participating teams as central. In complex operations in high-risk environments, inter- and intra- organizational coordination is a factor that can determine success or failure. Inter-organizational coordinating requires an orchestration of efforts during planning and execution phases of disaster management plan (Comfort & Kapucu, 2006; Kapucu et al., 2010). In disaster management, the standard for this is the "Incident Command System"

(ICS) (Boersma, Comfort, Groenendaal & Wolbers, 2014). ICS consists of a number of mandates and protocols describing communication and coordination between response organizations (Bigley & Roberts, 2001). Also in the training for crisis response ICS is used standard operating procedure for managing and coordinating activities. Both civil and military actors use it as formalized institutions, to facilitate collaboration among different actors in a response group. Despite the careful planning and the efforts made to create a holistic framework for facilitating coordination between the different stakeholders during response operations, reality shows a different picture. The coordination dynamics in response operations are not as rigid as defined by the ICS, instead they emerge as loosely coupled network formations named coordination-clusters. The coordination-clusters are a representation of executed tasks during response operations (Butts et al., 2010). For an illustrative case for this observation we refer for example to Noori et al, 2016 which studied with a network approach how the coordination cluster formatted in the disaster response to the Elbe river flood 2002 in Germany.

Secondly, another widely recognized issue is that many scenario based trainings provide an specific template for expected behavior and do not sufficiently consider designing scenarios which train to deal in an unusual situation where following specified procedures is not enough. Commonly, the scenario development is suspended before the beginning of the exercise. Consequently, there is little room for adaptive behavior and out-of-the box thinking (Reason, 1997). However, in today's world, characterized by unprecedented complexity and uncertainty, this is indispensable. Risks are hidden and opportunities and constraints may rapidly evolve, which brings high pressure to the current crisis management and response system. Hence, there is the need for alternative training methods that support organizations and individuals to interpret ambiguous situations and find innovative solutions to unexpected situations To our best knowledge, there is currently no approach to dynamically generate scenarios that focus specifically on this learning goals (Comes, Bertsch & French, 2013). Therefore, a dynamic approach to scenario design is needed that:

1. Focuses on the learning aims within and across organizations
2. Aims at revealing vulnerabilities inherent in the technical systems, processes and policies;
3. Recognizes the complexity and interconnectedness of today's socio-technical systems;
4. Is a continuous process that iteratively recognizes and adjusts to new information;

CASE STUDY: THE TRIPLEX-2016 EXERCISE

To complement the literature review, next through a case study we demonstrate properties and challenges of the scenario design processes. The selected case is not meant to be generally representative for the scenario-based training in the field of disaster response and emergency management but be an illustrative example.

Triplex is a 4-day humanitarian and civil protection exercise, triennial organized by the international humanitarian partnership (IHP), a network of seven European governmental emergency management agencies. As a team of researcher we joined the most recent simulation exercise taking place in Lista, Norway between 25 - 29 September 2016. In Triplex-2016 over 36 organizations working in the field of humanitarian aid and civil protection jointly trained the response to a simulated large-scale disaster. The main objectives of the TRIPLEX-2016 exercise were to: (1) simulate a training environment for humanitarian actors to exercise coordination, information management, assessment and other mission- related issues, and (2) train and exercise cooperation capacities and coordination mechanisms (e.g. UNDAC/cluster coordination) between humanitarian and civil protection actors. Participating agencies in the exercise included humanitarian United Nations (UN) agencies, iNGOs, and governmental civil protection agencies. According to the organizational team the objective of the exercise was to provide a safe learning and training environment, for exercising cooperation in humanitarian operations between civil protection, humanitarian organizations and other actors.

TRIPLEX-2016 exercise covered the following phases of response operations: (1) Arrival of the United Nations Disaster Assessment and Coordination (UNDAC) team and establishment of a UN Reception/Departure Centre, (2) arrival of international response teams at the airport and customs and immigration procedures, (3) establishment of the UN On-Site Operations Coordination Centre (OSOCC) registration and assignment of international response teams, (4) establishing inter-cluster coordination mechanisms in the key areas Food, Water and Sanitation (WASH), Logistics, and Health, (5) perform (joint) rescue operations and Multi Cluster Initial Rapid Assessment (MIRA), and (6) stakeholder management including host government and media.

For the process of evaluating the performance of the participants and the quality of the exercise itself, the organizers of TRIPLEX 2016 established a number of predefined roles in the exercise as set out below:

Exercise Control (EXCON): Responsible for managing and monitoring the whole exercise play, including the continual update of the inject list.

Response cell: Intermediary between participating organizations on the ground and EXCON core group. Responsible for permanently communicating all developments related to the ongoing and planned injects and events.

Controller: "Eyes and Ears" of EXCON in the field. Usually assigned to a specific participating organizations. Concerned with safeguarding that the exercise runs as planned.

Role players: Comprise of amateur actors (prevailing UN university students) that for each inject play a role and story according to a brief script. Exercise participants (practitioners) interact with amateur actors. For some injects professionals were playing their own role (e.g. local authorities of host government). A few inject were concerned only with internal processes and therefore did not require any role players but for most injects the interaction between role players and participants was essential.

Exercise evaluators: Exercise evaluators were usually a senior member of participating teams. They briefed the role players and assessed team's performance during each inject. For this the evaluator formulated expectations on the appropriate response to inject and observed whether they were matched. In addition, exercise evaluators facilitated the internal evaluation discussion.

Scenario Design and Planning Process at TRIPLEX 2016

The TRIPLEX 2016 planning process involved all participating organizations, and took more than a year, including three planning conferences and various workshops. Scenario planning was led by a core group and organized by the Norwegian Civil Protection Authority (DSB). The general outline of the disaster events were predetermined by the setting and context of the exercise at the sea in southern Norway. The basic scenario or backdrop assumed that a hurricane and heavy rainfall had hit the country causing major flooding and heavy damage in infrastructure and displacing hundred thousands of people.

The exercise itself focused on the initial relief phase and the days immediately after the disaster. In this period, international help started arriving in the affected nation and after setting up camps and equipment, rapid need assessments were undertaken and rescue operations performed.

After the initial deployment, the exercise was inject-driven. A role-play simulation in which amateur role-players improvised the interaction with responders following minimal scripts of pre-defined incidents created the experiential learning environment. Moreover, Norwegian local authorities were actively participating in the exercise by playing oneself. These injects and events were planned based on questionnaires for specific injects or situations that the individual organizations wanted to simulate and play. For instance, in some areas telecommunication, electricity and water supply were unavailable and people were trapped by floodwater and desperately waiting for rescue.

Scenario Implementation at TRIPLEX 2016

The exercise objectives were set out as to test and train the deployment and relief mechanisms following the UNDAC and ERCC guidelines and specifically exercise collaboration across organizations. We had many good and insightful conversations with practitioners during the exercise and after the exercise had completed conducted five interviews. The interviews were guided by interview guidelines. The official interviews and informal talks revealed that many practitioners perceived the exercise as meaningful. One interviewee stressed that the exercise purpose was not to use or test new training materials or innovative tools. The goal was to create an environment to facilitate collaboration within a larger community and to network with peers where an opportunity arises for meeting and learning about other humanitarian actors.

Interviewees also highlighted the importance of exercises like TRIPLEX 2016 in the learning and training process of newcomers. The TRIPLEX 2016 provided a sandbox and a learning opportunity for young professionals where they can observe and participate in response operations.

Impact of TRIPLEX-2016 Scenario Design Process on Exercise Execution

In addition to the data collected through the interview, the researchers team recorded several observations during the TRIPLEX 2016 execution. One of the main observations was related to the interorganizational coordination characteristics during the exercise. Unlike the patterns observed in real-world response operations, during the exercise, the coordination dynamics between participants appeared to follow different patterns. Participating organizations were occupied in applying their own methods and utilizing own technology or resources during the exercise. Although during the planning phase the goal was to improve the collaborative learning regarding communications and a unified situation-room. The intra-organizational coordination dynamics were more visible than the inter-organizational ones. In the TRIPLEX 2016 instructions, participants were instructed:

“

- During the exercise, participants should act according to their own, regular functions as if it was a real-life situation, i.e. a real emergency deployment.
- Participants should use the regular chain of command and communication channels that their respective organizations would use during an emergency deployment.

“

The instructions might contribute to the pattern observed during the exercise. Therefore, the choice of the scenario design and the language employed had an impact on teams’ behavior.

Repetition in scenarios selection from previous years (i.e. TRIPLEX 2013 or other training events) was another observation made by the team. Moreover, due to the absence of an automated process execute the scenarios, the participants had knowledge of the scenarios in advance and knew the injects associated with them. This might have had a negative impact on the performance because, in reality, disaster events develop following highly unexpected patterns. So the surprise factor and the instability conditions were lost during the simulation and the exercise’s capacity to increase preparedness was diminished.

Finally the evaluation process was performed in the teams within each organization in isolation from the others. It is important to gage the organization’s performance during such events, but more important is to gage the levels of dependencies on external organizations because it impacts on the performance teams too.

SCENARIO GENERATION FRAMEWORK FOR UNSTABLE ENVIRONMENTS

Generally, the function of scenario development can be differentiated into process-oriented and product-oriented (van Notten 2006). Process-oriented: facilitates learning, communication and improving observational skills and entangled the information overload to the essential. Learn from the past and reflect on uncertainties in the future. Product-oriented: Testing policy options by performing practice runs of possible future situations. Our approach goes a step beyond that by developing adaptive scenarios that change and adapt dynamically depending on the actions of the players.

From a design perspective, scenario developed should be *comprehensive* (scope of the entire exercise environment), *agile* (modular components that support adaptability and scalability), *valid* (quality metrics should be designed for scenario validation), and *effective* (task performance measurements).

Having an automated and adaptive scenario generator would provide an alternative to the existing approach in designing scenario-based exercise simulations. However, one of the challenges in dynamic settings is the unlimited number of scenarios that can be created. Therefore, there is a need to transform a limitless number of scenarios into a smaller set of manageable, and select the representative and most relevant injects to create a scenario tree tailored to the exercise at hand (see Figure 2). Each step of selecting a specific inject is thus understood as reducing the number of possible scenarios to a limited subset, analogous to the approaches used in branch & bound algorithms. Prioritization of injects is performed by calculating the potential learning of the possible scenario paths related to the selection and selecting the inject that maximizes the potential learning at each step, while ensuring that constraints (time, resources, skills) are met.

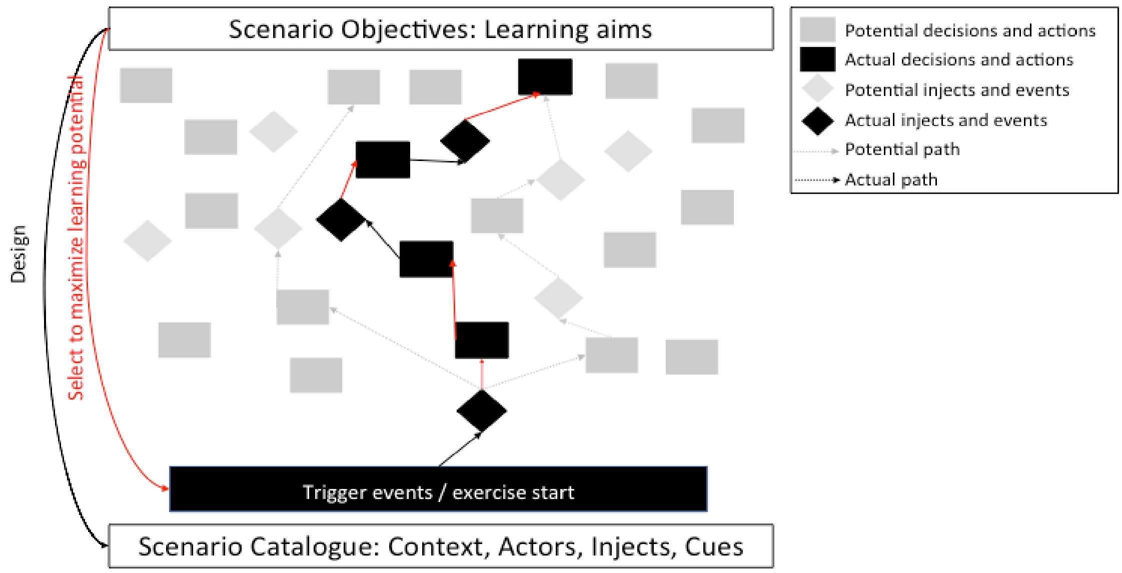

Figure 2: Scenario development as continuous real-time scenario selection to maximize learning potential

In Figure 3, we present a proposed framework to automate the process of scenario development. We distinguish between the scenario catalogue, which provides potential contexts and inserts, and the simulated scenarios, which are adapted in real-time to the actual behavior during the exercise. The heuristic data is stored using a scenario catalogue that contains elements like contexts, actors, injects and cues.

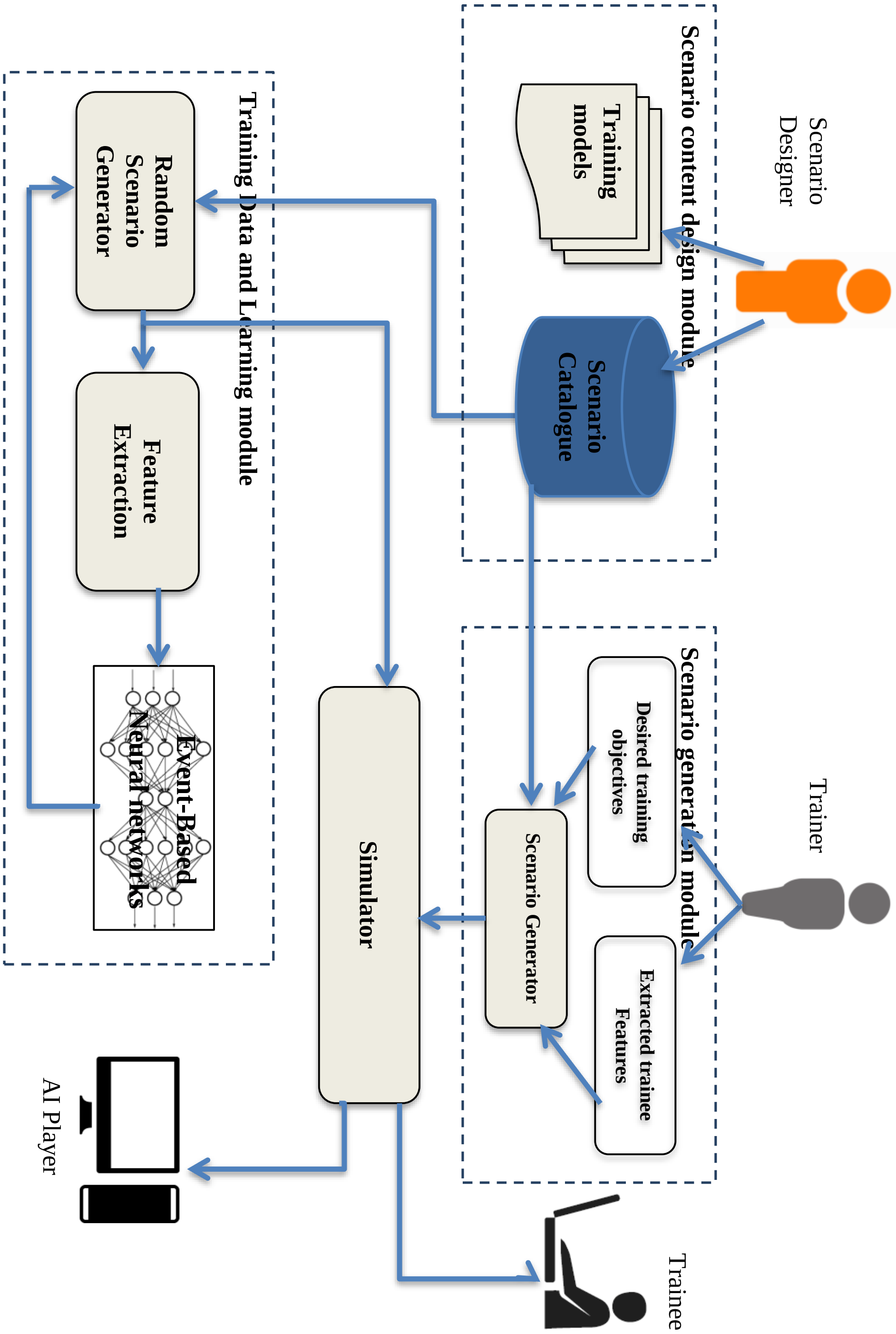

Figure 3. Proposed framework of an adaptive scenarios generator.

The conceptual design in Figure 3 shows the core elements of the framework for a scenario generator that can adapt the process of generating scenarios based on the changes in the environment. The basic design idea: create a 'scenario pool' (see Figure 2) with modular components from the following elements:

- Actor's features (local governments, UN agencies, iNGOs, NGOs, local communities, attackers, etc.)
- Training models and aims (improve decision making, avoid errors, etc.)
- Scenario features (contexts, threats, resources (assets, technologies, etc.))
- Cues (continuous and cross-operations related to training aims, trigger cue and response cue)

These elements will be further specified regarding contents, relationships and attributes like possibilities, level of impacts and training objective or goals.

The framework contains a *scenario contents design* module that provides both manual and automated capabilities of contents' authoring. The module comprise a *scenario template* consists of the elements mentioned earlier (i.e. actors, context, assets, cues, and injects etc). An automated training module would provide possible scenario elements for an adaptive scenario. Input from the *scenario catalogue* and heuristic data collected from participants' performance are used to train an *event-based neural network* system (Pedersen, Togelius, Yannakakis, 2010; Sahoo., Xu & Jagannathan, 2015). The participants' performance during exercises needs to be evaluated and logged (Thomas, et al., 2012), where it would be used to as in input for adapting and selecting the scenarios generated. The final module is the *simulator*, which aggregates contents from the scenario generation and training modules to produce new scenario path (or events sequence) that reflects changes in the environment and participants' response.

DISCUSSION AND CONCLUSION

The scenario-based exercise methods are gaining a great popularity in recent years due to technological advancements which made simulations and virtual environments creation much easier than before. However, the scenario-based training in the field of disaster management is still lagging because of the complex nature of conditions associated with a disaster event (Comes et al., 2011, Luo et al., 2014). The high levels of uncertainty and risk factors related to disaster events are not easy to simulate in real-time or to cover the limitless number of existing scenarios (Comes et al., 2015). The lag in creating scenarios satisfying requirements such as effectiveness, agility, comprehensiveness and adaptability leads to negative effects on the outcome of the exercise and the organization's' performance in the field (. As we saw from the coordination patterns observed during the TRIPLEX-2016 due to the language used and scenario selection and other factors. Instead of observing the emergence of task-based coordination clusters, organizations exhibited a silo effect like behavior when responded to injects during the exercise.

We reflect upon the issues observed during the exercise and proposed an automated approach in planning and generating scenario in real-time to help create simulations that reflect real-live situations. The proposed framework will help to improve the outcomes and strengthen the use of scenario-based training in disaster and emergency response. Using scenarios will help forecast possible risks and find proper ways to mitigate or respond to those conditions. Future work has to be conducted to test and validate our framework. Simulations aiming at humanitarian aid workers will be developed and observed for this purpose.

ACKNOWLEDGMENTS

The authors gratefully acknowledge their anonymous interview participants and the organizers of TRIPLEX - 2016 for all the efforts put into making this event a success and enabling our research by inviting us to participate. This research has partly been funded by the European Union's Horizon 2020 research and innovation program under grant agreement No 700510.

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Response and Recovery

Managerial Challenges in Early Disaster Response: The Case of the 2014 Oso/SR530 Landslide Disaster

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ABSTRACT

The larger the scale, scope, and duration of a disaster, the higher is the number of response units. However, with more units involved in the response also the heterogeneity of responder units drastically increases in terms of capabilities, experiences, practices, techniques, tactics, and procedures. As a result, the coordination and overall management of the response becomes an increasingly challenging endeavor. In the response to the 2014 Oso/SR530 landslide disaster in Washington State over one hundred agencies were involved, which presented a huge coordination task for the incident command. This empirical study is exploratory and focuses on the activities and interactions of professional responders, particularly, in the early phases of the response. It amends and complements previous studies on the subject by identifying and describing in detail various challenges in the early response. It also discusses recommendations on how to tackle and potentially mitigate the challenges identified in future responses.

Keywords

Incident Command System (ICS), National Incident Management System (NIMS), coordination challenges, resource challenges, training and preparedness challenges, collaboration, communication and information sharing.

INTRODUCTION

The most massive landslide (not attributable to volcanic activity) in the history of the United States occurred near Oso, Washington in the morning of Saturday, March 22, 2014 at about 1037 hours. Forty-three people lost their lives along with an unaccounted number of animals. Within a minute over fifty residential structures vanished from the face of the earth, and the Washington State Route 530 (SR530) was engulfed by mud and debris at a length of more than one mile (Lombardo, et al., 2014).

The enormity of the incident was only slowly understood, so it took the Governor ten days to request the declaration of national disaster from the President. The response and early recovery effort extended for almost three months, and the SR530 only opened to the public in late September that same year, after the mud and debris cover had been removed and the highway had been partly rebuilt. Even two years after the slide, the debris field is barren and uninhabitable.

The response involved a total of 119 agencies from all levels of government including the National Guard, the Coast Guard, the State Emergency Management Division, FEMA Region X, Snohomish County, the Department of Natural Resources, EPA, neighboring jurisdictions such as King and Pierce counties and the City of Seattle among others as well as dozens of relief organizations. Over one thousand individuals were part of the response.

When categorizing the Oso/SR530 disaster along the Fischer Scale (Fischer, 2003, p. 100), this incident can be classified between DC-4 and DC-5 (small town to small city with major scale, duration, and partial scope). It was not anywhere near a DC-8 (massive large city) disaster or a DC-9 catastrophe (affecting several densely populated areas). Nevertheless, the response to this DC-4-to-5 incident was enormous in scale and duration, and it required the mastery of highly complex managerial, operational, and tactical tasks.

Since 2004, the National Incident Management System (NIMS) with its core, the Incident Command System (ICS), has been mandated and used to facilitate and unify the coordination and management of emergency and disaster response across the United States (Anonymous, 2008). NIMS along with the National Response Framework of 2013, which “describes the principles, roles and responsibilities, and coordinating structures for delivering the core capabilities required to respond to an incident" (Anonymous, 2013, p. i), provide the nationwide foundations for responding to all kinds and scales of hazards in the US. ICS, when combined with other pillars of NIMS, including Preparedness and Resource Management, establishes a governance framework for multifunctional and multi-jurisdiction preparedness, response, recovery and mitigation. This framework of "good practices" is designed to provide an efficient means of delegation of authority, joint decision making, coordinated operations and resource management as well as information sharing. The emergency management community has adopted NIMS to mitigate challenges that are rife in ad-hoc or unstandardized planning and response. Standardized training is available for all levels of government (local, state, and national). Practitioners, that is, emergency managers and responders, however, emphasize that classroom training is imperative but is only effective if combined with planning, coordination, training, exercises, and, of course, real world experience.

While the mostly linear-hierarchical structure of NIMS/ICS appears highly robust and well-suited for smaller-scale and smaller-scope incidents such as wildfire responses, despite the strong support from the practitioner community, in academia it has been seriously questioned regarding its effectiveness and suitability for larger-scale, larger-scope, and longer-duration incident responses such as national disasters, and, in particular, catastrophes (Wenger, et al., 1990), for example, of the magnitude of the 2011 Eastern Japan earthquake-tsunami-nuclear incident.

Although a number of empirical studies have been conducted attempting to identify and understand the specific managerial challenges, which responders face in disasters of higher order (DC-3 and higher), the results are anything but clear-cut and rather at variance, somewhat vague, and high-level. By and large, practitioners are in support of NIMS (Cole, 2000; Hansen, 2007), whereas a number of academics have remained critical of the framework (Buck, et al., 2006; Kapucu, 2009; Waugh Jr, 2009). Yet, no clear evidence for the efficacy of NIMS/ICS or the systemic absence thereof has been produced by empirical studies in recent years.

The object of this study is to help further identify, describe, and understand specific managerial challenges in disaster response as they were observed and analyzed in the context of a DC-4/DC-5 category disaster. Furthermore, the study also focuses on the practice or absence of along with obstacles to use ICS and the NIMS framework in this particular disaster with the aim of assessing its acceptance and versatility in a fairly complex response.

For this study, first responders from several levels of government were interviewed, among whom were the local responders first on site, members of the Snohomish County Emergency Operating Center, the incident commanders, responders from neighboring municipalities and counties under mutual-aid agreements as well as urban search and rescue teams (USAR) along with the State Emergency Management Division (EMD), the WA National Guard, and FEMA Region X.

The paper is organized as follows: First, the extant literature on managerial challenges in disaster response and on NIMS/ICS is reviewed. Then, the study's research questions are outlined, followed by the methodology section. Next, detailed findings are presented. Finally, a discussion of the insights from the findings is presented, and conclusions are conferred along with directions for future research on the subject.

RELATED WORK

The challenges to organized behavior in the response to disasters has been studied for decades (Dynes, 1970; Dynes and Aguirre, 1979). Quarantelli pointed at three particular areas of concern, (a) information flows between and among responder units (particularly, in the context of inter-organizational and cross-jurisdictional information flows), (b) range and specificity of response tactics relative to the range and specificity of disasters, and as a result of these, (c) inter-organizational and cross-jurisdictional coordination problems (Quarantelli, 1988). In a later contribution the same author cautioned against the belief that information and communication technologies (ICTs) alone could completely address and potentially solve the information flow and coordination problems (Quarantelli, 1997).

Such worries notwithstanding, over the years practitioners and academicians alike have proposed and introduced ICTs as adequate means to help address and improve all three areas of concern in disaster preparedness and response. Socio-technical systems including decision-support systems have been proposed to improve all aspects of response management (Comfort, et al., 2004; Mendonca, et al., 2001; Militello, et al., 2007). Multiple empirical studies have confirmed and illustrated the centrality of information in coordinated disaster response (Bharosa, et al., 2010; Dawes, et al., 2004; Scholl, et al., 2017). Amongst the many obstacles for sharing information during disaster response the lack of pre-disaster aid agreements, different organizational cultures, time pressures during the response, information overload, bounded rationality under duress, tunnel vision and lack of big picture, and the lack of knowledge regarding information needs of other collaborating responders were repeatedly observed (Bigley and Roberts, 2001; Endsley, 1995; Kapucu, 2005; Scholl, et al., 2017). The simplification of the information process, the adherence to coordination and facilitation procedures, and the implementation of information filters have been proposed to deal with the observed complexity of the response (Kapucu, 2005).

On federal level within FEMA and its State-level equivalents such information sharing procedures had been developed to some fair degree; however, in the course of the forming of the Department of Homeland Security (DHS) and FEMA's fold-in into the then new organization many of these procedures might initially not have been maintained (Waugh and Streib, 2006).

As shown elsewhere (Endsley, 1995; Endsley, 2015; Endsley, 1995; Scholl, et al., 2017), both vertical and horizontal information sharing are prerequisites to shared situational awareness (SSA), which in turn allows for the development of a shared common operating picture (COP) that collaborating responder units, which do not necessarily belong the same jurisdictions during a response, are able to jointly adopt, and upon which they are enabled to base their coordinated response. Coordination of response efforts and collaboration of responder units, hence, ideally go hand in hand based on open communication and information sharing channels among them in both vertical and horizontal directions. However, as scale, scope, and duration of disasters (Fischer, 2003) increase, the complexity of collaboration, coordination, communication and information sharing also increases significantly (Chen, et al., 2008; Comfort, et al., 2004; Dawes, et al., 2004; Drabek and McEntire, 2002; Dynes and Aguirre, 1979).

As a case in point increased complexity of coordination, collaboration, communication and information sharing during the response to the 9/11 terrorist attacks has been reported in a number of studies of the account (Comfort, 2002; Dawes, et al., 2004; Kendra and Wachtendorf, 2003; Wachtendorf, 2004). As one of the reactions to the 9/11 attacks, in 2004 the Federal Government made the National Incident Management System (NIMS) and its core, the Incident Command System (ICS), a national framework and standard for the response to all hazards including man-made disasters (Tierney, 2009; US_Department_of_Homeland_Security, 2008; Waugh Jr, 2009). NIMS and its ICS core implement a predominantly hierarchical command and control structure representing an extension and further development of the original wildfire response-based ICS (Cole, 2000), which had been developed by firefighters over several decades (Stambler and Barbera, 2014). Despite its strong support by practitioners (Cole, 2000; DeCapua, 2007; Hansen, 2007) even the original wildfire-based ICS had drawn quite some criticism from various academics (Drabek and McEntire, 2002; Neal and Phillips, 1995; Wenger, et al., 1990) who saw the system prone to information losses and ill-suited for large-scale responses beyond a narrow set of tasks specifically pertaining to wildfires even before ICS was expanded and became the core of NIMS. In particular, the integration of non-governmental organizations and volunteers in the response was characterized as weak under ICS (Wenger, et al., 1990).

After the formal introduction of NIMS/ICS as national incident response framework and standard in 2004 the academic commentaries on the system did not become any more favorable, at least not immediately: While some scholars bemoaned a dilution of ICS within the new all-hazards framework (Stambler and Barbera, 2014), or, found information flows negatively impacted by the command-and-control structure (CCS) (Kapucu and Garayev, 2016; Kapucu and Hu, 2016), or, claimed a lack of equal effectiveness of NIMS/ICS across hazards other than wildfires (Jensen and Waugh, 2014), yet other scholars appear to have at least begun considering the aforementioned supportive practitioners' accounts along with a more empirical evidence-based approach to assessing and evaluating the emerging impact and effectiveness of NIMS/ICS (Jensen and Thompson, 2016). The latter two authors clearly indicate that they found the empirical basis for the extant academic evaluation of NIMS/ICS to be still extremely small. In particular, by not empirically covering the wide scale, scope, and duration of disasters (Fischer, 2003)it is difficult to draw any clearcut conclusions regarding the system and its effectiveness across hazards and disaster types.

Subsequently and as outlined above, this study's object is to help narrow the identified empirical gap by better understanding the specific managerial challenges during a DC-4/DC-5 disaster, that is, the 2014 Oso/SR530 Landslide disaster. In particular, the study investigates the uses (or, non-uses) of NIMS/ICS during the response, which leads to the following two research questions.

RESEARCH QUESTIONS

Research Question #1 (RQ#1): What were specific managerial challenges during the multi-agency/multi-level response to the 2014 Oso/SR530 Landslide?

Research Question #2 (RQ#2): What were the specific challenges regarding the use of NIMS/ICS during the multi-agency/multi-level response to the 2014 Oso/SR530 Landslide?

METHODOLOGY

Instrument and Coding Scheme

Based on the conceptual framework of resilient information infrastructures (RIIs) (Scholl and Patin, 2014), a semi-structured interview protocol was devised upfront, which covered six topical areas of (1) management and organization, (2) technology, (3) governance, (4) information, (5) information infrastructure, and (6) RIIs/resiliency. A total of thirty-six interview questions and probes were incorporated.

Sample

The sample was purposive (Ritchie, et al., 2003) and included responders from nine different groups: the (1) local responders, (2) County Emergency Operations Center, (3) urban search and rescue teams, (4) WA State (type-2) response teams, (5) responders from neighboring jurisdictions under mutual aid agreements, (6) State Emergency Management Division, (7) WA State Department of Transportation, (8) WA State National Guard, and (9) Federal

Emergency Management Agency (FEMA), region X. A total of 31 individuals were interviewed.

Data Collection

Interviews were conducted in person between September 2014 and March 2015 and lasted between 55 to 261 minutes. One interview was conducted via Skype video conferencing. All interviews were audiotaped, transcribed, and coded by at least two coders for analysis. During the interviews also notes were taken and participant interaction was observed and recorded. Moreover, other documents such as after-action reports and press interviews were collected, reviewed, and coded as appropriate.

Data Analysis and Coding

The initial codebook, which was based on the aforementioned conceptual RII framework, contained six category codes (one for each topical area) and 134 sub-category codes. Additional codes were inductively introduced during data collection, in individual coding sessions, and inter-coder sessions. Since a codebook in a hybrid approach of deductive and inductive analyses (Fereday and Muir-Cochrane, 2006) is designed to be open to extension, it ultimately encompassed 151 sub-category codes in the six main categories.

At least two researchers coded each transcript and document by means of a cloud-based software tool for qualitative and mixed-method data analyses (Dedoose main versions 6 and 7, dedoose.com). The coded data were compared one by one and demonstrated high inter-rater reliability.

The code frequency table revealed the highest numbers of code applications in the areas of “management and organization” (2,219), “technology” (968), and “information” (711). For the purpose of the specific analysis on managerial challenges the code intersection represented by the sub-codes of “managerial structure,” “address challenges of organizing,” and “address challenges of improvising” was selected, which produced a total of 928 excerpts for all nine distinct responder groups.

Excerpts, which were between two and three paragraphs in length, were organized per responder team and conceptually analyzed. Recurring themes and main concepts were identified and named by means of key phrases and keywords. These concepts/context clusters were transferred to the “canvas” of a cloud-based mapping tool (CMAP, version 6.01.01). The concepts/context clusters were inspected and sorted into topical “bins” or “baskets,” in which chronological, logical, and other relationships were identified. Relationship links between concepts/context clusters were established whenever evidence from the data supported that link.

Research Team and Processes

The research team consisted of the principal investigator (PI) and more than fifty research assistants (RAs), both for-credit and voluntary. The PI and RAs worked individually and in small teams to transcribe, code, and conceptually/contextually analyze, and map the concepts. The research team met weekly in person or online and communicated via the research project site and the project listserv as well as via individual face-to-face and group meetings. All weekly meetings were streamed and recorded, which kept the whole research team in sync over extended periods of time.

FINDINGS

Ad Research Question #1 *(What were specific managerial challenges during the multi-agency/multi-level response to the 2014 Oso/SR530 Landslide?)*

Overview of Response and Early Recovery

Unlike other emergencies and disasters such as earthquakes, high-wind storms, flooding, wildfires, and “regular” mudslides, for which responders in the Northwest region of the United States are routinely and relatively well prepared, the 2014 Oso/SR530 landslide marked an exception in terms of scale and scope, and finally, also duration (with regard to the recovery effort necessary). Responders’ acquaintance to seasonal mudslides, particularly, after extended periods of precipitation, had made those emergencies a routine response endeavor. So, when the disastrous landslide occurred in the late morning hours of Saturday, March 22, 2014, the incident did not trigger an immediate non-routine response, since the order of magnitude of the slide was not understood until much later that day, and its ramifications became only clear after days had passed by. As discussed elsewhere (Scholl, et al., 2017), situational awareness and a common operating picture were only slowly developing, so that responders initially acted mostly on information that presented itself right in front of them. Helicopter rescue crews, for example, although aware of the geographical extent of the disaster, focused first and foremost on searching for and rescuing lives rather than sharing information with other layers of emergency management to create a bigger picture. Likewise, although the responders on the ground palpably experienced the enormity of the damage, they hardly comprehended the enormous destruction along with the dilation and depth of the muddy and treacherous debris field right in front of them. Moreover, since the massive landslide had physically divided the whole valley into two separate entities within a minute’s time by deeply burying the highway at a length of a mile, by disrupting the communication connections, and also by extirpating all identifiable landmarks, the management of the incident was highly difficult and complex from the first moment.

Until darkness made further search and rescue operations impossible on the first day, local responders primarily organized and executed the response. In the interviews they pointed out how uncertain they had felt about the extent of their own responsibility. They further reported about what they had perceived as a lack of clarity regarding processes and procedures. The local responders also described their confusion with regard to how to request resources and support from outside their jurisdiction and the County. Interestingly, the Snohomish County EOC never fully activated during the response and recovery and was left unmanaged by the director of the County Department of Emergency Management. According to EOC personnel, initially and in the absence of any respective preplanning for an incident of that particular caliber, experienced a sense of disconnectedness and disorganization with regard to personnel assignments. As a result, instead of functioning as a hub of coordination and information sharing, the EOC was said to rather have hoarded valuable information and processed resource requests slowly. Adding to the complication, the County's Office of Medical Examiner, when facing mass fatalities for the first time and without respective planning either, turned to a mode of non-cooperation and non-collaboration with other response units including towards the County EOC. This stance would not significantly change even in the following weeks.

On the day after the massive landslide had occurred (day 2), a regional type-3 incident management team (IMT) took over from the completely overwhelmed and exhausted local responders. Meanwhile the State Emergency Operations Center had been fully activated, and FEMA Region X had begun to tentatively, that is, without request, deploy assets and an incident support team to the disaster site. Also, under various mutual aid agreements responders from neighboring jurisdictions arrived at the disaster site. On day 5 (Wednesday, March 26), it became finally clear that the incident was larger than any type-3 IMT could handle, and a State-level type-2 IMT was activated, which shadowed the type-3 team on day 6 (Thursday, March 27) and took over the management of the incident response the following day. The type-2 IMT's expertise lay predominantly in the area of fighting wildfires rather than in complex urban search and rescue operations and respective tactics, which were much needed in this particular incident response. By the time the first type-2 IMT had assumed the management of the response, the Washington National Guard (WANG) had over one hundred personnel on the ground on various missions. Activated WANG personnel would more than triple in number over the next weeks. Urban Search and Rescue Task Force teams were brought in along with FEMA support teams among quite a few others. With the massive influx of response personnel and equipment, however, the coordination task quickly became huge. The first type-2 IMT was replaced by a second type-2 IMT on day 20 (Thursday, April 10). Finally, a month after the incident had happened, the regional type-3 IMT was reactivated and took over the management of the recovery effort.

Coordination, Communication, and Collaboration Challenges

Jurisdictions and Functional Responsibilities

Although compact, relatively small, and in mostly unincorporated county territory, the remote one square-mile area impacted by the landslide spanned several jurisdictions: Snohomish County, the Washington State Department of Transportation (State Route 530) and Washington State Patrol, the US Coast Guard (North Fork of the Stillaguamish River), City Light of the City of Seattle (with respect to the maintenance and access road to power feeder lines along the valley), and several federal agencies such as the Environmental Protection Agency (EPA) and the Department of Natural Resources (DNR) among others. Furthermore, functional responsibilities involved various fire districts around the incident area including the City of Arlington and the town of Darrington. Arlington was also involved with regard to suspected downriver effects, and Darrington was concerned with regard to upriver flooding and affected by transportation cutoff.

The Evolution of a Unified Command Structure During the Response

In part due to the unclear jurisdictional scope, in other part owed to slowly increasing situational awareness and only partial comprehension of the incident's magnitude, a unified command structure evolved in several phases. While the initial local responders (Oso and Darrington fire stations, and Snohomish County Fire District 21) and the Snohomish County Sheriff's Helicopter Rescue Team were on site within less than an hour after the landslide had occurred, on day 1 the coordination between responders on the ground and in the air was minimal, which changed the next day when the regional type-3 IMT took over the management of the incident response and provided superior operational capabilities. The type-3 team operated out of the EOC established at Arlington City Hall. Said one local responder on the ground,

> "When I got to the EOC, I didn't know what Northwest IMT meant, what they did. So I quickly had to learn who these guys were. We did a lot of unified command stuff, but I was not aware that you could call a group of people to come in and manage an incident like that. That was the first big hurdle for me to learn. The second hurdle was ensuring that all the players that needed to be involved were there." (quote #01)

However, the absence of local knowledge regarding the roles and functions of IMTs and the formal aspects of unified command were compounded by the County EOC's disapproval of decisions made at the incident command post (ICP), for example, regarding the involvement of volunteer experts from the Darrington timber company who helped cut up tumbled trees on the debris field. Likewise, the County resource request processes and procedures appear to have been cumbersome in the first days, if not in first two weeks. Another local responder's response illustrates the problems with establishing a unified command and the tensions between the County EOC and the ICP,

> "So I called over there <that is, the County EOC> and said, listen, we are using them <the volunteers>, period, you can go pound sand... We got to a point of just, screw the system, I don't care about that, I care about getting <needed resources>...and we did. And then <County EOC> logistics they were getting pissed. All right, then get me what we need." <insertions by authors> (quote #02)

The Snohomish County EOC appeared to be caught rather flat-footed by the incident. The director of the County Office of Emergency Management strangely refrained from personally engaging in managing the EOC response operations, but rather left this task to a newly hired deputy who was unfamiliar with both premises and players. As one responder remembered,

> "When I got there on Monday afternoon <day 3, March 24, 2014>, the EOC in my opinion was in a disarray. It was not organized, there was instant command really set up in there. H. was trying to put the pieces together, but she was a new employee, and she didn't know anybody, she didn't have those relationships built. Another challenge was that the county as an organization did not support their emergency management group well." <insertions by authors> (quote #03)

Responders called in under mutual-aid agreements reported that Snohomish County EOC neither issued update reports nor took systematic efforts to share information resulting in skewed information flows, which led to an inability to react to the cascading effects of the still unfolding disaster. The mutual-aid responders also pointed at a lack of transparency regarding task assignments and resource request tracking. Under these circumstances, a unified command structure, which integrated and coordinated the burgeoning influx of responders and resources from outside the jurisdiction, evolved slowly. This would only change when the County under the heavy burden of the response and relieved by the State disaster declaration finally agreed to have the first State-level type-2 IMT take over incident response management and operational coordination on day 6.

When the first State-level type-2 IMT took over responsibility, a unified command structure, which coordinated all response units, finally evolved further, but not without ongoing challenges. For example, still, the lack of compatible radio channels and technical breakdowns would hamper communications. Still, not all response units would have a clear understanding of their assigned roles. Still, uncoordinated and unauthorized public communications would go out. And still, information sharing outside the ICP situation room was difficult. As the incident commander observed,

> "There wasn't really a way that anybody else would know that unless you were right in the command room. There wasn't any posting of that information. There wasn't any dissemination, there really wasn't, so that all the people working the incident had a common operating picture. You know, I just don't, there's just didn't have the organization to do that, or the technology, or that infrastructure that would be required." (quote #04)

The fact that the incident response was managed from the ICP on the Arlington side of the debris field with only a satellite on the Darrington side (which due to the state route cutoff was hard to reach on the ground) caused some frustration on the latter side. Not only was the town's culture with its own mayor and structure very different from Arlington, but the officials and responders felt left out of the loop and not equally included although the response on the Eastern half of the debris field was operated from the Darrington side. Rather than creating an area command structure, the incident commander later deployed a deputy commander to the Darrington side, which was obviously seen as a more parsimonious approach. However, still frictions remained throughout the response, since the debris barrage and the state route cutoff negatively impacted the up-valley communities for months.

Effects of Unwillingness to Collaborate

While most responders reported of great willingness and commitment to collaboration among diverse teams during the response, several groups (including the County EOC) found working with the County's Medical Examiner (ME) had been extraordinarily difficult. While the Office of the ME claimed exclusive jurisdiction over handling all fatalities, at the same time it obviously failed to provide instructions, procedures, plans, or facilities for handling extracted human and animal corpses and body parts. As a result, the urban search and rescue task force (USARTF) had to improvise plans and even set up a makeshift morgue. Said one USARTF commander,

> "In this incident, the medical examiner never showed up, so all investigation was handled by the task force, all documentation was handled by the task force, and we did a great job. I'm very proud of the job that was done. But that's not what we normally do. Normally we find them, extract them, you know, to a place that ... even before we extract them there's somebody documenting it. But in this case, there was none of that. We handled it, and then, in addition, we handled all the protocol for how were we going to move them in the presence of family, in the presence of relatives, and there were no policies that were established by command." (quote #05)

Lack of Standardized Resource Request Procedures

Also, resource request procedures would still not be standardized and effective, and on part of the IMT the County EOC was seen as a difficult partner in the transition. As the first incident commander summed it up,

> "For the first couple of days that we were there, to make sure that we were all on the same page with all of the agencies and people who had been in charge are now following our lead and then working with the County EOC and making sure, we were on the same page with them, was probably the most challenging thing we had." (quote #06)

Interviewees from the Washington State EMD also acknowledged a lack of interagency and inter-level coordination and collaboration due to the lack of practice and rehearsal in large-scale incident response except for responders from FEMA region X. The unified command structure could have been implemented earlier, had the type-2 IMT been activated and involved earlier. The non-standardization of resource request procedures statewide along with insecurity about the source of funding, particularly in the area of search and rescue, was identified as problematic and in need of change. According to one EMD responder, resource requests stalled,

> "So the incident management team requests something, and they request it because it's an operational need for something for them to be able to do something. In the EOC, the question will come up, OK, how are we going to pay for this? And the fact that, you know, if there's doubt — how can we pay for this, or how is this going to work? — that, then, all of a sudden can stall filling the request." (quote #07)

The Problem of Scaling-up the Response Effort

Federal responders from FEMA region X also identified coordination and collaboration problems, which made it difficult to form a unified command early and effectively, part of which were seen as attributable to turf struggles over competencies and jurisdictional reach between State and County, while other problems related to the lack of preparedness at local levels. However, the federal side had difficulties of their own with integrating into a unified command, since not all federal agencies involved would embrace the federal requirement of being coordinated by FEMA in their response efforts. Yet, as mentioned FEMA region X had preemptively moved numerous assets and resources close to the disaster site, but had to hold back on committing them until requested by the State. Yet, the requests came with a substantial and unnecessary delay (from a FEMA perspective). As one FEMA interviewee stated,

> "I think that they <the County and State> thought they could manage it the whole way through. And they really tried to keep control, and I think that things would have gone better if they had asked for help earlier or at all. Because, the help they asked for was very limited, they kind of cafeteria style of I want a little bit of this a little bit of that, and they didn't want to full robust response. It wouldn't have made any difference in saving lives, but I felt the response overall could've gone better in the early stages if they had asked for help earlier. I felt like by the time they had stated asking for help they were already behind." <insertion by authors> (quote #08)

In summary, specific managerial challenges in the response included a lack of comprehending the magnitude of the disaster at local and State levels accompanied by a lack of preparedness at local levels for a disaster of that particular type and magnitude. Further challenges included the confusion over jurisdictional responsibilities and the slow forming of unified command, which would have allowed to assign tasks more effectively, request and deploy resources in a timely fashion, and ramp up the capabilities as necessary more quickly across levels and jurisdictions.

Mitigation of Challenges in Coordination, Communication, and Collaboration

Across teams responders emphasized that better information sharing and information integration would have greatly helped overcome the challenges in coordination, communication, and collaboration. Many interviewees emphasized the importance of in-person and over-the-phone meetings. However, it was said that relying on the spoken word alone would not suffice, but rather systematic integration of relevant and consolidated information (including visualization) was essential, which then had to be disseminated or made accessible vertically and horizontally. Developing pre-disaster face-to-face relationships (via exercises and meetings) was seen as a key pre-requisite to successful coordination and collaboration. Interviewees also stated that using stickers, vests, or other visual identifiers would have helped to determine any individual's role at the ICP, the EOC, as well as on and around the debris field. Inter-agency and inter-team communication as a pre-requisite for coordination and collaboration during the response can also be improved by systematically deploying liaisons who embed with the respective other units and make the inter-organizational connection work. Said one State EMD officer,

> "This is another lesson learned, that we need to do far more work in terms of preparing our liaison officers, making sure that they have the horsepower to go out there and speak for the agency, and that our expectations of them are very clearly understood. So we put somebody into the County EOC immediately, and we rotated folks through there, and they did a good job. If I had it to do over again, I would put a person in the EOC and I would also put another person in the incident command post." (quote #09)

Ad Research Question #2 *(What were the specific challenges regarding the use of NIMS/ICS during the multi-agency/multi-level response to the 2014 Oso/SR530 Landslide?)*

The Lack of Training and Experience with NIMS/ICS

While Washington State EMD and quite a number of county and city EOCs in the State had embraced NIMS/ICS and the National Response Framework (NRF), others such as Snohomish County EOC, public works, or the police had not had any systematic ICS training at the time the landslide occurred. The military, that is, the National Guard, although deeply involved in the response, had its own command structure, and did not use NIMS/ICS structures and procedures. However, in particular, local responders in the impact area had had no formal training in ICS and NIMS-related structure, procedures, and principles prior to the incident. This lack of training showed in the response to the landslide. The principle of unified command was initially not fully embraced. Furthermore, neither the local responders nor the County EOC were prepared to connect with the incoming mutual-aid responders, the various task forces, the type-2 IMTs, and the State agencies on the basis of NIMS/ICS. Absent respective training, no ICS-related planning and no ICS-compatible forms had been prepared. Said one County EOC deputy in hindsight,

> "One of the things I'm going to have them do is I'm going to have them go back to ICS forms. On a day-to-day basis, on their computers. I'd like to see them actually make some ICS forms that look like ICS forms, so when their guys are coming in and logging in in the morning doing different things, they're looking at an ICS form. Because then you know what? When we have the disaster and we hand out an ICS form, they know what it is! If we're going to have tools that we only pull off the shelf in a disaster, one of two things is going to happen: we're not going to know how to use them, or they're going to be broken. Or missing. So whatever you come up with, it has to be something that we can integrate into the system today to some extent and get the people utilizing it. And if you can't, I don't think you'll be successful." (quote #10)

Confusion Between NIMS/ICS and ESFs

Before this backdrop, it was only consequential that the County EOC had serious problems with coordinating the county-wide emergency support functions (ESFs), which coordinate county agencies' and others' support in the case of an emergency, and with integrating them into the ICS structure, which the type-2 IMT and other responder teams expected to be used. This became particularly evident in the handling of resource requests and in the disjoint of logistical structures causing tremendous confusion, multiple ordering, delays, and unnecessary tensions over who was entitled to make what decision. As one mutual-aid responder described the situation,

> "In the EOC, I was kind of amazed at how informal it was when I first got there…Who's in charge? I told all of the responder guys together and all of our PIOs, both personally in the field on our side of things, as well as during the conference calls. I said, 'Guys, there's only one correct answer to this question. It is the incident commander. The incident commander works for the county. He's in charge of all this.'" (quote #11)

The Lack of Standardization in NIMS/ICS and Rising Complexity in Larger Incidents

While NIMS/ICS provides a general frame of structure and procedure, the details of implementation can still vary to some extent, which can make the actual management of an incident response difficult. In so-called home-rule states such as Washington State, where local jurisdictions maintain the final say over a response and over what slices of responsibilities are effectively delegated to incident commanders, the effective management of a response can become fairly complex and even cumbersome, particularly, if the delegation of authority is only partial. As one senior EMD officer stated,

> "It took a while to get a formalized delegation of authority to the IMT, Snohomish County kept the public messaging piece and the resource ordering piece. So, you know, immediately, you have two major functions of an IMT that is not part of the delegation of authority, which tended to interrupt their normal way of doing business, because they now had touch points with the Snohomish County EOC that are not part of their normal procedures." (quote #12)

The delegation of authority in a small incident is a straightforward undertaking, for example, in the case of a wildfire-engulfed small municipality all authority necessary is transferred from the mayor to the IMT. In larger events, this delegation is a far more complex undertaking, and more entities are and remain involved in the decision-making process. Besides the jurisdictional and organizational complexities, which NIMS/ICS mitigates in part, during this response teams also had to work together using a plethora of different technology platforms and only partly interoperable information and communication systems (ICTs) as already reported elsewhere (Scholl, et al., 2017), which made the complex response undertaking even more challenging.

Mitigation of Challenges Regarding the Use of NIMS/ICS

According to responders from almost all levels and teams, more ICS-related training and more frequent exercises and rehearsals using the ICS structure and procedures down to the local levels would make a major difference in preparedness. It became clear in the interviews that the vast majority of responders accepted and welcomed the use of NIMS/ICS as a framework and tool. It was also stated that the integration of ESFs into the ICS structures needed more attention. Moreover, interviewees noted that the use of NIMS/ICS in an all-hazard (rather than predominantly wildfire) settings needed to be practiced and further developed. In particular, the USAR Task Force found the type-2 IMT too wildfire oriented and not familiar enough with the requirements and all aspects of urban search and rescue missions. Said one USAR TF commander,

> "The direction that we get from the incident management team normally would be through the form of an incident action plan. And that's the way the incident commander communicates their expectations to the people who are responding. In our case, we published a task force tactical action plan, and we developed our own search planning effort for the first two weeks. And even after the first two weeks, when the incident management team started creating an incident action plan that they shared with us, they still, when it came time to planning the search effort and deciding how we were going to proceed, they still left that to us to decide." (quote #13)

DISCUSSION AND CONCLUSIONS

With a total of 119 government agencies and non-governmental entities involved, the DC-4/DC-5 magnitude disaster, which struck the Steelhead Drive community near Oso, WA on March 22, 2014, triggered one of the most comprehensive multi-agency response efforts in the history of Washington State. Since scale and scope of this type of incident was unprecedented in the State and County's history, responders were not specifically prepared by ex-ante planning nor previous experience, which forced them to improvise also with regard to coordinating their efforts, communicating with each other, and collaborating on a scale and scope, only few of the over 1,100 responders had ever experienced before. As the findings show, information integration and communication problems, both technical, organizational, and procedural, were at the core of a resulting asymmetry of information distribution leading to a lack of a shared common operating picture (COP), which in turn initially hampered effective response coordination and collaboration.

Intense information sharing as a prerequisite for the coordination of efforts across multiple levels and areas of responsibility (Comfort, et al., 2004), however, requires the effective integration of shared information into a shared COP. The technical basis in terms of integrated radio and voice communications among responders, which accounts for the lion's share of all response communication, was not immediately available and only established after several days into the response. Moreover, the systems used for integrating voice and data, for documenting, for resource requesting, and for consolidating data into actionable information at the ICP, EOC, as well as the supporting units were not easily interoperable, produced enormous amounts of reduplication and error, and required a lot of creative improvisation. Making information and communication systems interoperable and standardizing resource request forms and procedures appear as important steps towards more effective response coordination, which the State's 2014 SR 530 Landslide Commission Final Report (Lombardo, et al., 2014) also found. However, while integrating responders' radio channels and modernizing voice and data communication capabilities (via FirstNet, www.firstnet.gov, and Washington's implementation, OneNet, https://onenet.wa.gov) along with standardizing resource request mechanisms are necessary statewide measures, which address important lessons learned from the incident, the integration and exchangeability, and maybe even, standardization of forms, templates, and documents used in information systems within the operations, planning, logistics, and finance sections as well as in the various IMT and EOC staff functions appear as consequential further steps.

Such integration and standardization of applications used on information systems could help further propagate and unify implementations of NIMS/ICS structures and procedures. The variety of NIMS/ICS implementations, to which responders from various response units were accustomed, presented problems, which, however, were minor compared to the complete absence of NIMS/ICS-related practice and basic understanding observed at the local levels during the incident. As many interviewees repeatedly expressed, more ICS training and more NIMS-based practical exercises would have been desirable before the incident and would have made a major positive difference. However, practical exercises were said to be time and cost intensive, which would present a steep barrier for smaller and less resourceful jurisdictions, unless funding was secured from external sources such as the State or the Feds.

Yet, despite ample NIMS/ICS expertise and experience from practice, responder teams may still bring fairly different task and hazard-specific experiences to the table. It was noted that the type-2 IMTs predominantly had specific wildfire fighting experiences, which would not easily translate to dealing with other hazards such as landslides or earthquakes as effectively. During the incident response this absence of hazard-specific experience became visible when the urban search and rescue task forces interacted with and unsuccessfully looked for direction by the IMT and finally decided to make their own plans and execute them without coordination by the IMT. So, similar to extending and intensifying NIMS/ICS training across responder communities and beyond its traditional origin in the emergency support function 4 (fire fighting), the extended training for "all" hazards will be a time and cost intensive undertaking.

In the Oso/SR 530 landslide response, the described deficiencies notwithstanding, the extent, to which NIMS/ICS was known and practiced, had a positive influence on coordination and collaboration between fairly diverse response units including non-governmental organizations such as the American Red Cross, which had also embraced and trained along the lines of NIMS/ICS. In contrast, the National Guard had had initial difficulties collaborating on the basis of NIMS/ICS, which led to a number of misunderstandings and coordination problems. These difficulties were attributed to the different (military) core mission of the Guard, which implicates its respective own command structures and procedures that are not specifically attuned to emergency and disaster responses. Interestingly, the Guard concluded from the incident to at least train Guard liaison officers and other personnel in NIMS/ICS in order to better coordinate with non-military responders during future incidents.

As outlined above, the overriding skepticism and outright rejection, with which NIMS/ICS had been met by very prominent and fairly outspoken members of the academic disaster research community in the US (Buck, et al., 2006; Dynes and Aguirre, 1979; Wenger, et al., 1990) until very recently (Jensen and Thompson, 2016), stands in stark contrast to the overwhelming support of NIMS/ICS in the US practitioner community (Cole, 2000; DeCapua, 2007; Hansen, 2007). Also in this study, not a single responder in the Oso/SR530 landslide who was interviewed related any of the above reported coordination, collaboration, or communication problems to NIMS/ICS; but rather to the contrary, the interviewees firmly held that given better training and more practical experience with the framework, its structure, and its procedures on part of all responders involved, would have made the response more effective and better coordinated much earlier.

The notion in the literature that NIMS/ICS solely represents a rather hierarchical command and control structure appears to be correct only at face value. As Hansen observed, in any given practical response the incident command system rather needs tweaking and adjusting to the particular needs and specific requirements of the disaster at hand. Furthermore, given that most resources and support capabilities in the response are provided through the horizontal structure of the fifteen emergency support functions (ESFs) and the military, the disaster response organization rather resembles a multi-layered matrix organization, in which multiple stakeholders with various and sometimes overlapping authority and influence congregate and form a unified command (including area commands, if necessary), which becomes more effective and efficient the more all players understand the structure and its procedures. Advocates of spontaneous disaster response self-organization seemingly disregard that disaster response management, after all, is, not in a small way, a sizable budgetary, fiscal, and economic undertaking, where somebody has to pick up and pay a massive bill in the end. In the US, in the majority of cases and for the most part this will be the federal taxpayer. However, this implies that control with regard to orderly, responsible, and restrained spending of funds and resources needs to be secured via due processes and procedures, which NIMS/ICS is chartered to provide.

This study’s object was to report on the specific managerial challenges of a recent major disaster in the Pacific Northwest of the United States. In particular, the study intended to produce additional empirical evidence with regard to the effectiveness of the much criticized National Incident Management System, and its core, the Incident Command System, which became the national standard for response operations in the US in 2004.

The authors would like to note that they are currently studying the Cascadia Rising exercise of 2016—the largest catastrophic emergency exercise in United States’ history, which, unlike the DC-4/DC-5 magnitude disaster as the Oso/SR530 landslide, mimics a DC-9/DC-10 magnitude catastrophic incident. This study will complement our earlier efforts as several participants in the Cascadia Rising exercise also responded to the Oso landslide. We anticipate that this follow-up study will reveal some of the improvements made as a result of lessons learned documented in the after-action reports including our research of the landslide. In addition, we expect that chronic or systemic issues might surface again or become further supported by empirical evidence, thereby complementing our research of the Oso landslide.

In summary and in conclusion, this study of the Oso/SR530 landslide response suggests that beyond wildfire fighting, NIMS/ICS appears to work reasonably well, at least, when responding to a massive landslide incident of a scale and scope of a DC-4/DC-5 disaster (Fischer, 2003). This assessment even holds despite the relative unpreparedness and unfamiliarity with NIMS/ICS of local responders, provided regional and State response capabilities are experienced enough using the NIMS/ICS structure and procedures. In future research, the authors intend to study the specific managerial challenges along with the challenges regarding situational awareness and the development of a shared common operating picture in the context of a large-scale exercise mimicking a DC-9 catastrophic event.

ACKNOWLEDGMENT

The following research assistants participated in the transcribing, coding, concept analyzing and mapping of the interviews: Stephanie E Ballard, Jorge Borunda, Ammi Bui, Hyung Jin Byoun, Tim Carlson, Sarah L Carnes, Sarah Carrier, Yi Fan Chang, Tiffany Chiu, Tiffany B Coulson, Amanda Cummings, Heather Diaz, Ryan Dzakovic, Sherry Shiyu Gao, Andy Herman, Akashdeep Singh Jaswal, Harsh Keswani, Tanu Khandelwal, Cassondra Koldewyn, Divya Kothari, Priyanka Kshirsagar, Janani Kumar, Deborah Kyle, Josephine Lau, Kung Jin Lee, Lysia Li, Chang Jay Liu, Audrey Lorberfeld, Ying Lu, Elan May Rinck, Randi L Mendel, Grace Morris, Veslava Ovendale, Neal Parker, Liz Pritchard, Deepa Sudarshan Rao, Dan Ray, Jorge Retamales, Tricia M Rhodes, Rashmi Sharma, Yuzhou Shen, Gagandeep Singh, Leili E Slutz, Emily K Smalligan, Louis C Spinelli, Sonal Srivastava, Rebecca Ta, Jenna Telvik, Huong Thanh Thai, Emily Thompson, Xiaobin Tuo, Aubrey Walter, Vaibhav Walvekar, Grant Woods, Fan Yang, April Ybarra, Katiana D Yeo, Yunjie Zhou, Yao Zhou, and several graduate assistants from Graduate Assistants Team.

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Decision Support for Search and Rescue Response Planning

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ABSTRACT

Planning, controlling and coordinating search and rescue operations is complex and time is crucial for survivors who must be found quickly. The search planning phase is especially important when the location of the incident is unknown. We propose, implement, solve, and evaluate mathematical models for the multiple rectangular search area problem. The objective is to define optimal or near-optimal feasible search areas for the available search and rescue units that maximize the probability of success. We compare our new model to an existing model on problem instances of realistic size. Our results show that we are able to generate, in a reasonable time, near optimal operationally feasible plans for searches conducted in vast open spaces. In an operational context, this research can increase the chances of finding survivors. Ultimately, as our models get implemented in the Canadian Coast Guard search planning tool, this can translate into more lives being saved.

Keywords

Search and Rescue response, search planning, optimization, mixed-integer linear program, multiple rectangular search area

INTRODUCTION

The act of searching is an important part of many humanitarian operations such as Search and Rescue (SAR) and mine counter measures, and of many surveillance operations for the purpose of protecting individuals, the environment, resources or infrastructures. Search and Rescue Units (SRU) including aircraft and vessels, teams of searchers, autonomous unmanned vehicles, may search for survivors, land or underwater mines, environmental spills, illicit activities, or abnormal behaviors. But how and where to search? The answer lies in good and efficient search planning that ensures the best use of scarce and constrained search resources. Search planning includes the definition of search areas and/or search paths in a way that maximizes the chances of an operation's success, often in degraded and rapidly changing conditions, in the presence of uncertainty on the whereabouts, the detectability, and on the conditions of the survivors, the threats, or the search objects.

In response to a distress incident, after having established plausible hypotheses regarding what might have happened and where, a SAR mission coordinator (SMC) must deal with the logistics of the search operations by allocating the available resources to search the established area of interest. The need for specific decision support systems that can assist a SMC in both the scenario and hypotheses building phase and the resource allocation phase has long been identified in Canada and elsewhere (Abi-Zeid and Frost 2005; Abi-Zeid, Nilo, Schvartz, et al. 2010; Aronica et al. 2010; Kratzke et al. 2010; Stone, Keller, et al. 2014; Małyszko and Wielgosz 2016; Bellantuono et al. 2016). Although both phases are of equal importance, we focus our research on resource allocation that mainly involves optimal search planning using search theory.

Search theory was one of the earliest Operations Research disciplines studied in the United States to address detection search problems (Stone, Royset, et al. 2016). As a matter of fact, it has been known, since the Second World War, that significant gains in search effectiveness are possible through the use of search theory. Frost and Stone 2001 presents many examples where search plans based on search theory did much better than less scientific methods. This was also demonstrated by Abi-Zeid and Frost 2005 where the use of a planning approach based on search theory was an improvement, in terms of the probability of success, over manual search planning methods. In addition, Ferguson 2008 reported that statistics have shown a significant increase in the number of lives preserved as a result of applying search theory concepts while more recently, Stone, Keller, et al. 2014 described how the application of search theory has helped locate the wreckage of AF 447. Search theory is also used in the area of autonomous searching by robots in structured environments, and by unmanned air vehicles for outdoor searching of large areas (Lau et al. 2008; Sato and Royset 2010; Kriheli et al. 2016; Venkatesan 2016; Bernardini et al. 2017).

A frequent practice in SAR response is to allocate search aircraft flying at the same altitudes to non-overlapping rectangular areas. This particular formulation of the search problem is known in the scientific literature as the Multiple Rectangular Search Areas (MRSA) problem (Discenza 1978; Abi-Zeid, Nilo, and Lamontagne 2011) where a grid of cells is superimposed over the search environment. A solution to the MRSA problem, also called a *search plan*, consists then of assigning SRUs to rectangles. A search plan is optimal if it maximizes the probability of finding lost search object(s), e.g., persons in water and/or missing vessels.

Very few papers have addressed the MRSA problem, a challenging optimization problem when many SRUs are present, when the area of interest is large, and when a fine grid with a small cell size is required. The literature contains various approaches including mixed-integer linear programming (MILP) (Discenza 1978) and constraint programming (CP) (Abi-Zeid, Nilo, and Lamontagne 2011). Discenza 1978 applied a heuristic to manage complexity by eliminating rows in the constraint matrix in order to obtain a matrix with the integral property (all the extreme points of the constraint polyhedron are integer valued). However, this reduces the set of feasible search plans and the optimal solution could be discarded by the reduction process. Furthermore, it does not take into account operational constraints. Richardson and Discenza 1980 proposed algorithms for the MRSA problem that could be applied to a maximum of five search units with cell sizes of 360 square Nautical Miles (NM^2). Abi-Zeid, Nilo, and Lamontagne 2011 designed and applied algorithms based on CP to obtain operationally feasible plans and used filtering heuristics to remove non-promising rectangles from the search space before using the CP solver. Their cell size of 25 NM^2 was more realistic.

In this paper, we revisit and reevaluate the performance of the MILP model proposed by (Discenza 1978) where rectangles are explicitly enumerated (MILP-Ex) and compare it against our proposed (MILP-Im) formulation based on an implicit definition of the rectangular search areas, implemented in two variants, with and without a startup heuristic. The work presented in this paper has served as a basis to obtain an ongoing contract to develop a search planning methodology to be integrated in an operational search planning system used in response to maritime SAR incidents in Canada.

This paper is structured as follows. We present search theory elements and the MRSA problem in the Background section. In the Methodology section we describe the (MILP) formulations. The following sections contain the experiments, results and discussion as well as the conclusion.

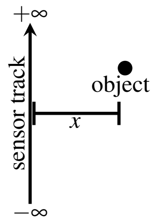
BACKGROUND – SEARCH THEORY AND THE MRSA PROBLEM

Broadly speaking, available search effort is the quantification of the resources available for searching. In SAR operations, this is normally the available on-scene endurance of a SRU. Search effort is allocated to subareas of the search environment in order to maximize a figure of merit, such as the global probability of finding the search object(s), also called the probability of success (POS), subject to operational and physical constraints. In the MRSA problem formulation we consider, the allocated search effort, tracked individually for each SRU, is measured in distance units. Since a constant search speed is assumed for each SRU, this is equivalent to on-scene endurance. The MRSA problem normally deals with K SRUs. To each SRU $k \in \{1, \ldots, \mathrm{K}\}$ corresponds a total effort E_k, in distance units, to be deployed over the search environment which is discretized by a grid consisting of cells.

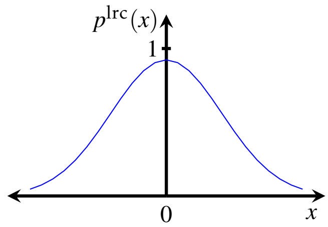
Let $\mathcal{R}$ be the set of all rectangular search areas over a search grid of M rows and N columns for a total of

$$|\mathcal{R}| = \frac{\mathrm{M}(\mathrm{M}+1)\mathrm{N}(\mathrm{N}+1)}{4} \tag{1}$$

possible rectangular search areas. A search plan assigns each SRU to a single rectangular search area for a total of $O\left((|\mathcal{R}|)^{\mathrm{K}}\right)$ possible search plans (feasible or not).



(a) A single sensor track



(b) A lateral range curve (fictional)

Figure 1. An illustration of the concept of lateral range curve

Given a fixed amount of effort E_k, many factors can influence the performance of SRU k in rectangle r. In search theory, all these factors reduce to a single conditional probability of detecting a specific object type over a specific area under specific conditions given that the object is in the area searched.

In order to derive the conditional probability of detection, we introduce two core concepts: the lateral range curve and the sweep width (detectability index). The efficiency of a sensor can be characterized by a lateral range curve: Suppose that a sensor is traveling along a straight line (track) at a constant speed. The *lateral range curve* $p^{\mathrm{lrc}}(x)$ gives the probability that a search object is detected along a search track as a function of the distance x at its closest point of approach. It is not a probability density function nor is it a cumulative density function. The underlying hypothesis is that the sensor's (searcher) track is infinitely long, in both directions (Figure 1). The area under the *lateral range curve* is called the sweep width. The larger the sweep width, the more efficient the sensor. The *sweep width* is defined as the integral of $p^{\mathrm{lrc}}(x)$ over x on the interval $[-\infty, \infty]$, $\int_{-\infty}^{\infty} p^{\mathrm{lrc}}(x)\,\mathrm{d}x$.

A probability of containment POC_{ij}, also called probability of whereabouts, is assumed to be known a priori for all cells (i, j) of the grid. This is the probability that the search object is in cell (i, j). The probability of containment of a rectangle $r \in \mathcal{R}$ is the sum of the cell probabilities that it contains:

$$\mathrm{rpoc}(r) = \sum_{(i,j)\in r} \mathrm{POC}_{ij} \tag{2}$$

An exponential detection function, that yields a lower bound on the probability of detection, is often assumed in optimization algorithms (Stone, Royset, et al. 2016). It is a function of the amount of effort e deployed in rectangle r and of the sweep width W of a sensor-search object combination under precise environmental conditions as follows:

$$\mathrm{rpod}(e, r) = 1 - \exp\left(\frac{-\mathrm{W} \cdot e}{|r| \cdot \mathrm{A}}\right) \tag{3}$$

where A is the area of a single cell and $|r|$ is the number of cells in rectangle r. A constant sweep width of W is assumed during the search, a realistic assumption for maritime SAR. It can be seen, from Eq. (3), that the detection probability increases with W. The same is true for the amount of effort e. It can also be seen that the probability of detection function follows the law of diminishing returns. The conditional probability of detection, as described above, does not take into account the probability of whereabouts. However, the probability of success, defined below, considers both probabilities.

The probability of success of a search unit inside a rectangular search area r is the product of probability of the search object being located there (probability of containment) and that a detection occurs (conditional probability of detection). That is, given a rectangle $r \in \mathcal{R}$ and a SRU k, we have

$$\mathrm{rpos}(\mathrm{E}_k, r) = \mathrm{rpoc}(r) \cdot \mathrm{rpod}(\mathrm{E}_k, r) \tag{4}$$

where E_k is the effort deployed by SRU k in rectangle r.

Let $\mathcal{A}$ be the set of all possible assignments of a SRU to a rectangular search area. The overall probability of success of the search plan $s \in \mathcal{A}^{\mathrm{K}}$ with K non-overlapping rectangles is the sum of the success probabilities local to each rectangular area. The objective of the MRSA problem is to maximize the probability of success of a search plan consisting of a set of SRU-rectangle assignments over the search grid as defined by Eq. (5).

$$\max_{\{r_1,\ldots,r_{\mathrm{K}}\}\in\mathcal{A}^{\mathrm{K}}} \sum_{k=1}^{\mathrm{K}} \mathrm{rpos}(\mathrm{E}_k, r_k) \tag{5}$$

subject to non-overlapping constraints. The formulation of this problem first appeared in (Discenza 1978).

Operational and Physical Constraints

In practice, SAR mission coordinators aim at achieving an area coverage factor of around 1. This is the dimensionless ratio of the area effectively searched to the physical size of the area searched. Given a total amount of effort E_k for SRU k, we define the coverage factor of k in rectangle r as:

$$\mathrm{cov}(r,k) = \frac{\mathrm{W} \cdot \mathrm{E}_k}{|r| \cdot \mathrm{A}} \tag{6}$$

This is a measure of how thoroughly a search area is covered independently of any prior knowledge on the object's whereabouts. When a SRU follows a parallel-track search pattern, further constraints on the spacing of the parallel tracks can be added. Recalling that the search effort deployed by a SRU k, E_k, is the total track length in distance units and that the area of a rectangle r is $|r| \cdot \mathrm{A}$, we define the track spacing of SRU k in rectangle r as:

$$\mathrm{tracks}(r,k) = \frac{|r| \cdot \mathrm{A}}{\mathrm{E}_k} \tag{7}$$

By constraining the track spacing to be larger than some lower bound, we ensure that the turning radius is big enough for the search pattern to be feasible. These supplementary constraints, not found in (Discenza 1978), can be added to further restrict the set of feasible search plans $\mathcal{A}^{\mathrm{K}}$ (Abi-Zeid, Nilo, Schvartz, et al. 2010).

METHODOLOGY – SOLVING THE MRSA PROBLEM FOR SAR RESPONSE

In this section, we present two MILP formulations of the MRSA problem. The first formulation, MILP-Ex, requires an explicit enumeration of all the feasible rectangles in the search grid and is attributed to Discenza 1978. The second formulation, MILP-Im, is novel. It is based on the idea of using constraints to implicitly model rectangles and then letting the solver perform the enumeration of the rectangles under the assumption of a constant sweep width. Furthermore, we describe a myopic heuristic algorithm that can be used to provide a startup solution to the (MILP-Im) model.

MILP with Explicit Enumeration of Rectangular Search Areas (MILP-Ex)

To build this model, we first compute the probability of success $\mathrm{rpos}(\mathrm{E}_k, r)$ obtained by a SRU k when it is assigned to rectangle r, for all rectangles $r \in \mathcal{R}$ and SRUs $k \in \{1, \ldots, \mathrm{K}\}$. We then define a set of binary variables to encode the assignment of SRU k to a given rectangle r as follows:

- $RECT_r^k$ equals 1 if SRU k is assigned to rectangle r in the search plan and to 0 otherwise.

This leads us to the following MILP:

$$\max_{RECT} \sum_{(r,k)\in\mathcal{A}} \mathrm{rpos}(\mathrm{E}_k, r) \cdot RECT_r^k \tag{8}$$

subject to Constraints (9) to (10) where $RECT_r^k$ is a binary variable. Each cell of the grid is constrained to belong to a single assignment:

$$\sum_{(r,k)\in\mathcal{A}} RECT_r^k \cdot [(i,j) \in r] \leq 1 \qquad \forall (i,j) \in C \tag{9}$$

where $[(i,j) \in r]$ equals 1 if cell (i,j) is in rectangle r and 0 otherwise. Constraint (10) forces each SRU k to be assigned to a single rectangle:

$$\sum_{r\in\mathcal{A}_k} RECT_r^k \leq 1 \qquad \forall k \in \{1,\ldots,\mathrm{K}\} \tag{10}$$

$\mathcal{A}_k$ is the set of all rectangles such that rectangle r is assigned to SRU k in $\mathcal{A}$:

$$\mathcal{A}_k = \{r \mid (r,k) \in \mathcal{A}\} \tag{11}$$

The total number of feasible assignments in $\mathcal{A}_k$ can be reduced by applying the operational constraints from Eq. (6) and Eq. (7) leading to a simpler MILP.

MILP with Implicit Enumeration of the Rectangular Search Areas (MILP-Im)

We first describe the variables and the constraints needed to create k non-overlapping rectangles. We then add the constraints required to compute the objective function.

Constructing Non-Overlapping Rectangles

We construct k non-overlapping rectangles using Constraints 12 to 28. Consider the following variables encoding the membership of a cell to a rectangle, to a row, and to a column:

- $X_{ij}^k \in \{0, 1\}$ is equal to 1 if the cell (i, j) belongs to rectangle k and to 0 otherwise
- $ROW_i^k \in \{0, 1\}$ is equal to 1 if row i belongs to rectangle k and to 0 otherwise
- $COL_j^k \in \{0, 1\}$ is equal to 1 if column j belongs to rectangle k and to 0 otherwise

The following constraints ensure that a given cell (i, j) belongs to rectangle k if and only if row i and column j belong to rectangle k:

$$X_{ij}^k \geq ROW_i^k + COL_j^k - 1 \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}\}, j \in \{1, \ldots, \mathrm{N}\} \tag{12}$$

$$X_{ij}^k \leq ROW_i^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}\}, j \in \{1, \ldots, \mathrm{N}\} \tag{13}$$

$$X_{ij}^k \leq COL_j^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}\}, j \in \{1, \ldots, \mathrm{N}\} \tag{14}$$

Note that given a SRU k and a 4 by 5 search grid, and based on the above constraints, the following

$$X^k = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{15}$$

would be invalid. However, although they do not define rectangles, the following

$$X^k = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{16}$$

and

$$X^k = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \end{pmatrix} \tag{17}$$

are valid. To avoid such situations, we introduce variables specifying the boundaries of a rectangle as follows:

- $\overline{ROW}_i^k \in \{0, 1\}$ is equal to 1 if the rectangle begins at a row i' with $i' \leq i$ and to 0 otherwise
- $\underline{ROW}_i^k \in \{0, 1\}$ is equal to 1 if the rectangle ends at a row i' with $i' \geq i$ and to 0 otherwise
- $\overline{COL}_j^k \in \{0, 1\}$ is equal to 1 if the rectangle begins at a column j' with $j' \leq j$ and to 0 otherwise
- $\underline{COL}_j^k \in \{0, 1\}$ is equal to 1 if the rectangle ends at a column j' with $j' \geq j$ and to 0 otherwise

We then add Constraints (18) and (19) to avoid skipping rows, and Constraints (20) and (21) to avoid skipping columns:

$$\overline{ROW}_i^k \leq \overline{ROW}_{i+1}^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}-1\} \quad (18)$$

$$\underline{ROW}_i^k \geq \underline{ROW}_{i+1}^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}-1\} \quad (19)$$

$$\overline{COL}_j^k \leq \overline{COL}_{j+1}^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, j \in \{1, \ldots, \mathrm{N}-1\} \quad (20)$$

$$\underline{COL}_j^k \geq \underline{COL}_{j+1}^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, j \in \{1, \ldots, \mathrm{N}-1\} \quad (21)$$

Let $\bar{i}$ and $\underline{i}$ correspond to the rows where rectangle k begins and ends. The following constraints state that row i belongs to a rectangle k iff $\bar{i} \leq i \leq \underline{i}$:

$$ROW_i^k \geq \overline{ROW}_i^k + \underline{ROW}_i^k - 1 \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}\} \quad (22)$$

$$\overline{ROW}_i^k \geq ROW_i^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, i \in \{1, \ldots, \mathrm{M}\} \quad (23)$$

$$\underline{ROW}_i^k \geq ROW_i^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, r \in \{1, \ldots, \mathrm{M}\} \quad (24)$$

The following constraints are the same as above, but for columns.

$$COL_j^k \geq \overline{COL}_j^k + \underline{COL}_j^k - 1 \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, j \in \{1, \ldots, \mathrm{N}\} \quad (25)$$

$$\overline{COL}_j^k \geq COL_j^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, j \in \{1, \ldots, \mathrm{N}\} \quad (26)$$

$$\underline{COL}_j^k \geq COL_j^k \qquad \forall k \in \{1, \ldots, \mathrm{K}\}, j \in \{1, \ldots, \mathrm{N}\} \quad (27)$$

Finally, we need a set of k non-overlapping rectangles as enforced by Constraint (28):

$$\sum_{k \in \{1, \ldots, \mathrm{K}\}} X_{ij}^k \leq 1 \qquad \forall i \in \{1, \ldots, \mathrm{M}\}, j \in \{1, \ldots, \mathrm{N}\} \quad (28)$$

The Objective function of MILP-Im

The objective function of the MILP-Im model is built on the assumption that the sweep width is constant across the search grid. This assumption holds for maritime SAR when the environmental conditions (e.g., weather, crew fatigue) are constant during the search operations. Instead of enumerating, as with the MILP-Ex model, all the feasible SRU-rectangle assignments to compute their probability of success, we leave this task to the solver. We still need to compute the probability of detection prior to the solving process. However, since the sweep width is assumed constant, we only need to store it for all possible rectangle sizes in number of cells for each SRU. Therefore, instead of generating $O(|\mathcal{R}| \cdot \mathrm{K}) = O\left(\mathrm{M}^2\mathrm{N}^2\mathrm{K}\right)$ assignments and probability of success values, we store and generate $O(\mathrm{MNK})$ variables. Using $POS_{ij}^k \in [0.0, 1.0]$, the probability of success in cell (i, j) of search grid C for SRU k, we get the following objective function:

$$\max_{POS} \sum_{k=1}^{\mathrm{K}} \sum_{(i,j) \in C} POS_{ij}^k \quad (29)$$

In order to compute the value of the POS variables, we define the following binary variables:

- Y_a^k equals 1 if SRU k is assigned to a rectangle of a cells and to 0 otherwise.

We also add two supplementary binary variables sets to help in encoding the linear constraints of the Y variables as follows:

- U_a^k equals 1 if SRU k is assigned to a rectangle with less than (or with exactly) a cells and to 0 otherwise.
- L_a^k equals 1 if SRU k is assigned to a rectangle with more than (or with exactly) a cells and to 0 otherwise.

Next, we add Constraints (30) to (33) where $\hat{\mathrm{M}}$ is a sufficiently large number, and where $\mathcal{R}^{\text{areas}}$ is the set of possible rectangle sizes a:

$$a - \sum_{(i,j)\in C} X_{ij}^k \leq \hat{\mathrm{M}}\left(1 - U_a^k\right) \qquad \forall k \in \{1,\ldots,\mathrm{K}\}, a \in \mathcal{R}^{\text{areas}} \quad (30)$$

$$\sum_{(i,j)\in C} X_{ij}^k - a \leq \hat{\mathrm{M}}\left(1 - L_a^k\right) \qquad \forall k \in \{1,\ldots,\mathrm{K}\}, a \in \mathcal{R}^{\text{areas}} \quad (31)$$

$$U_a^k + L_a^k = 2Y_a^k \qquad \forall k \in \{1,\ldots,\mathrm{K}\}, a \in \mathcal{R}^{\text{areas}} \quad (32)$$

$$\sum_{a\in\mathcal{R}^{\text{areas}}} Y_a^k = 1 \qquad \forall k \in \{1,\ldots,\mathrm{K}\} \quad (33)$$

We constrain the value of the POS variables using the indicator variables of a rectangle size by Constraint (34):

$$POS_{ij}^k - \mathrm{POC}_{ij} \cdot \mathrm{pod}(\frac{1}{a}\mathrm{E}_k, (i,j)) \leq \hat{\mathrm{M}}\left(1 - Y_a^k\right) \qquad \forall k \in \{1,\ldots,\mathrm{K}\}, a \in \mathcal{R}^{\text{areas}}, (i,j) \in C \quad (34)$$

Furthermore, Constraint (35) forces the probability of success of a SRU k in a cell (i,j) to be null if k is not located in (i,j):

$$POS_{ij}^k \leq X_{ij}^k \qquad \forall k \in \{1,\ldots,\mathrm{K}\}, (i,j) \in C \quad (35)$$

Finally, the set $\mathcal{R}^{\text{areas}}$ is restricted using operational constraints described in Eq. (6) and Eq. (7).

The MILP-Im with a Myopic Heuristic Based on the Probability of Success (MILP-ImH)

In order to jump-start the MILP-Im, we propose a simple myopic heuristic for the MRSA problem that first consists of enumerating all the rectangles and computing the probability of success of each SRU-rectangle assignment. Second, the SRU-rectangle assignment with the highest POS is chosen as part of the search plan. This heuristic can provide a good starting solution for the MILP-Im and is computed in polynomial time. We call the implementation of MILP-Im with this heuristic the MILP-ImH model.

EXPERIMENTS

Since time is of the utmost importance when lives are at risk following a SAR incident, it is crucial that any decision support for operational search planning yield good search plans in a short time period. We therefore conducted experiments to evaluate and compare performances in terms of solution quality and execution time using realistic search areas. We conducted experiments using the two models presented above, i.e., the model with enumerated rectangles (Discenza 1978) with additional operational constraints and our novel formulation with an implicit enumeration of the rectangles. In total, we compared the performance of three variants of the models (MILP-Ex, MILP-Im, and MILP-ImH) in terms of the objective function value (probability of success) attained within 15 minutes, and of the time required to obtain that solution. The experimental framework was developed in C++ and built upon the IBM ILOG CPLEX solver version 12.6.1. The comparison was conducted on the following four grid instances:

- grid A: 13 by 17 cells, a total area of 5,525 NM^2 (18,950 km^2);
- grid B: 7 by 95 cells, a total area of 16,625 NM^2 (57,022 km^2);
- grid C: 30 by 30 cells, a total area of 22,500 NM^2 (77,173 km^2); and
- grid D: 47 by 49 cells, a total area of 57,575 NM^2 (197,476 km^2).

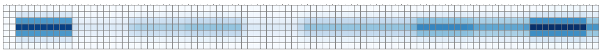


Figure 2. The whereabouts of a search object on a grid of 7 by 95 cells (grid B)

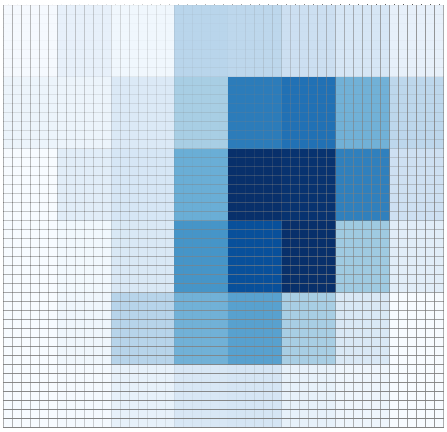


Figure 3. The whereabouts of a search object on a grid of 47 by 49 cells (grid D)

Each of the grids has a different distribution of the whereabouts of the search object (probability of containment). As an illustration, we present on Figures 2 and 3, the probability of containment of grids B and D respectively. A darker color cell has a higher probability of containment. For each grid, we generated two problem instances, one with 4 SRUs, and one with 5 SRUs. We applied the coverage constraint to reduce the solution space by enforcing a coverage such that $.5 \leq \text{cov}(r, k) \leq 2.5$, for all rectangles r and SRUs k. We also included track spacing constraints such that .5 NM $\leq \text{tracks}(r, k) \leq 2.5$ NM for all rectangles r and SRUs k to guarantee feasible search plans. It should be noted that the above constraints are realistic operational constraints.

Results and Discussion

The optimal value of the probability of success depends on the problem instance. To facilitate the comparison across instances of different sizes (both in terms of the number of SRUs involved and in terms the total number of cells in the grids), of different probabilities of containment and of different sweep widths, we present the percentage of improvement achieved by each incumbent solution. For each problem instance, the highest known objective value corresponds to a 100 % improvement. Figures 4 to 7 present the percentage of the best objective achieved versus the preparation and the solving time in seconds. The preparation time includes the time required to generate the model and to load it into memory. For the MILP-ImH, this also includes the time required to run the myopic heuristic that provides a starting solution. We chose to include the preparation time in the comparison since SAR operations are time critical. A decision support system based on a MILP solver for SAR planning needs to prepare the model first before solving it. In such a practical context, it is therefore important to identify the models that are more time-consuming to prepare.

By looking at the instances in an increasing order of complexity (from Figures 4 to 7), we notice that the MILP-Ex model scales poorly in comparison to the MILP-Im model. It is true, however, that the MILP-Ex model enables the solver to find high quality solutions much faster than the MILP-Im model on sufficiently small problem instances, e.g., on the instances of grid A. For the larger instances, i.e., the ones of grids C and D, the MILP-Ex model does not fit into memory which justifies the need for an alternative model as the size of the problem increases. The MILP-Im model consumes less memory and less time in the preparation phase. It thus has the advantage of allowing the solver to quickly start its search for solutions, which is critical for SAR response management since an SMC might need to stop the solver earlier to task the SRUs, or to try multiple scenarios which involves generating different MILP models. In an operational SAR setting, it is generally agreed that a first executable search plan should be found within 3 minutes. One problem that remains when using the MILP-Im model alone is that the first few solutions found by the solver might be low quality solutions, i.e., a low probability of success. By using a heuristic, we can provide a good starting point for the solver which is exactly what is done when using the MILP-ImH model.

Figure 8 shows the search plans obtained with 5 SRUs on grid B. Each rectangle corresponds to an area assigned to a SRU. The search plan of Figure 8a is the one returned by the myopic heuristic (the first solution of MILP-ImH). The search plans of Figures 8b, 8c and 8d are the best search plans found within 15 minutes (900 seconds) when

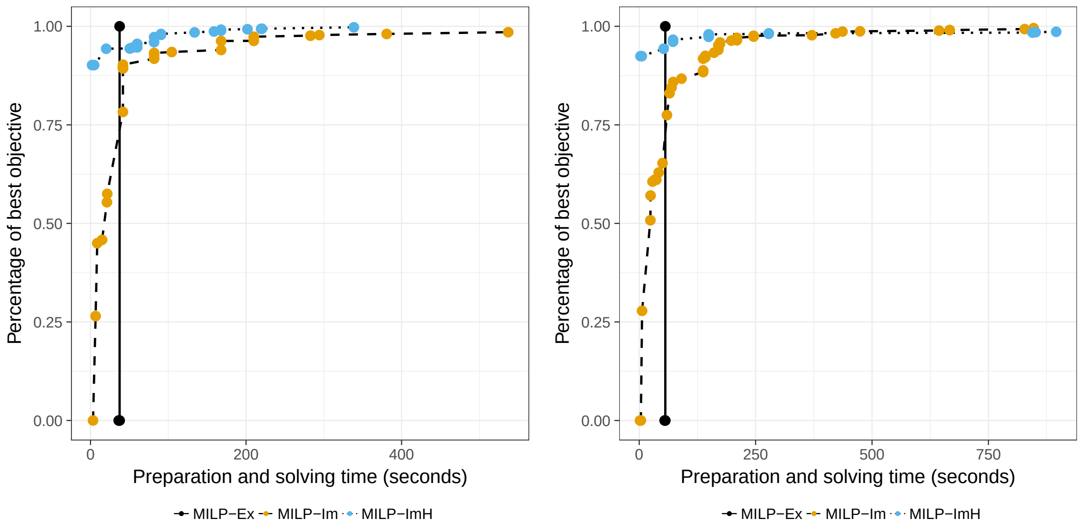


Figure 4. Grid A: 13 by 17 cells with 4 SRUs (left) and 5 SRUs (right)

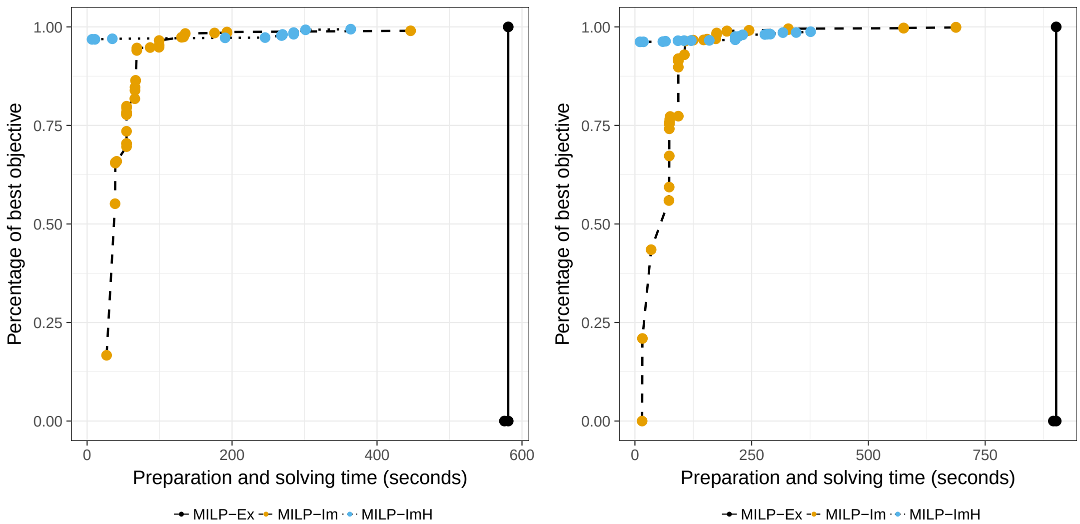


Figure 5. Grid B: 7 by 95 cells with 4 SRUs (left) and 5 SRUs (right)

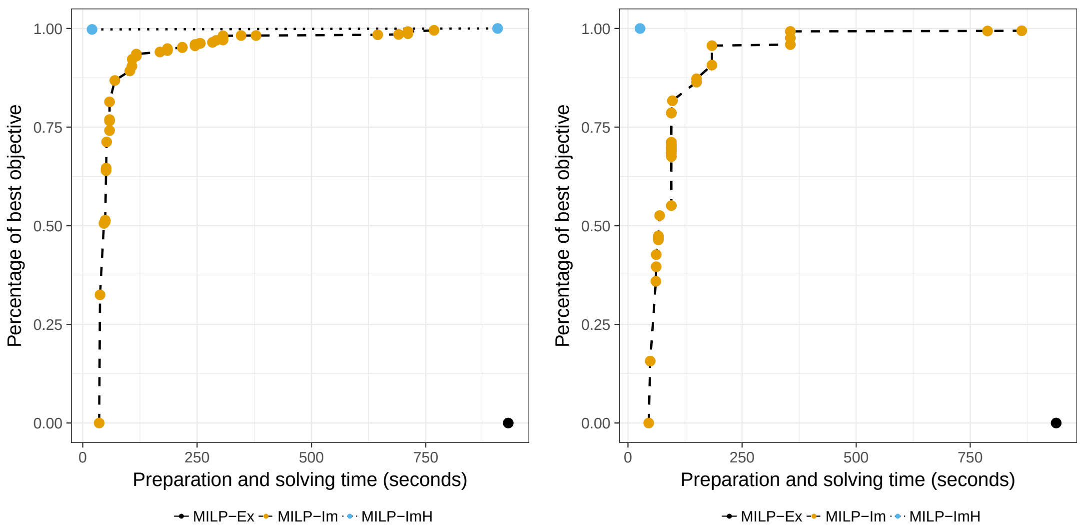


Figure 6. Grid C: 30 by 30 cells with 4 SRUs (left) and 5 SRUs (right)

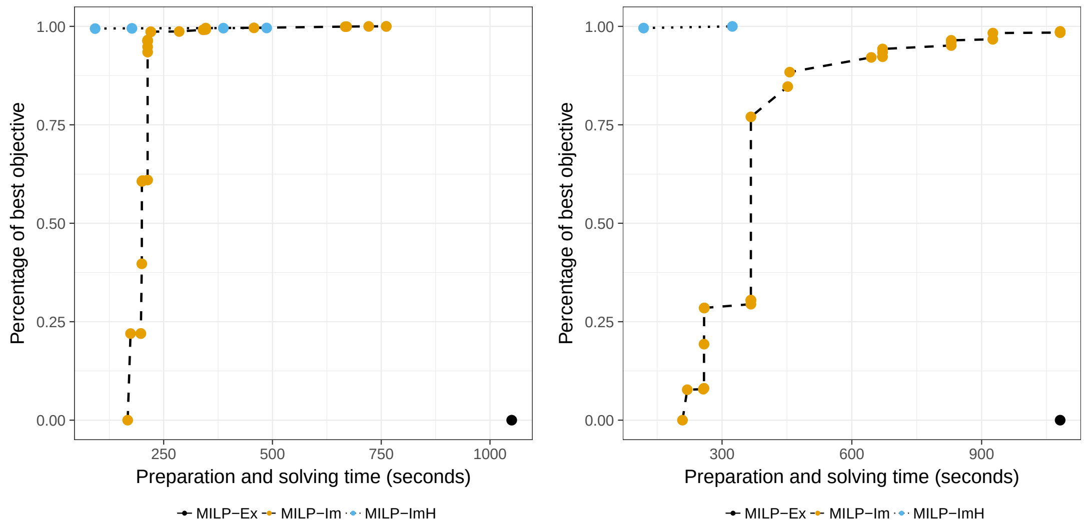
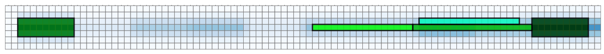
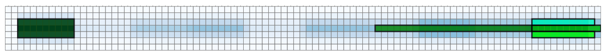


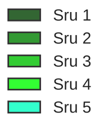
Figure 7. Grid D: 47 by 49 cells with 4 SRUs (left) and 5 SRUs (right)

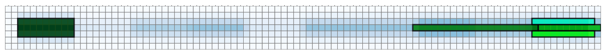


(a) Myopic heuristic search plan,
96 % of improvement after 1 second

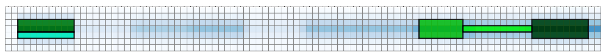


(b) MILP-Ex search plan,
100 % of improvement after 896 seconds (including preparation time)





(c) MILP-Im search plan,
98 % of improvement after 684 seconds (including preparation time)

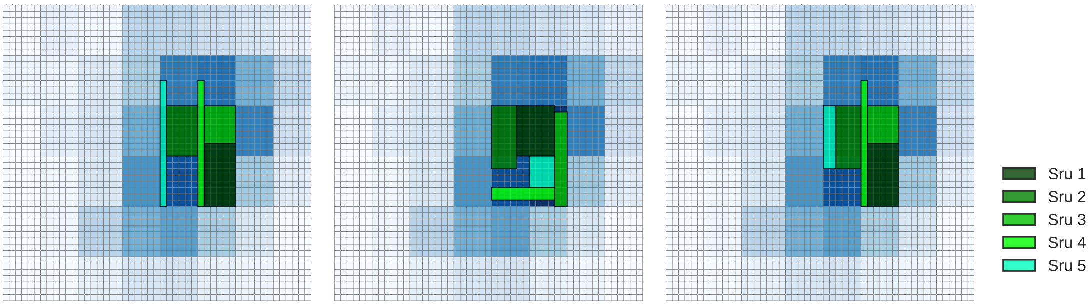


(d) MILP-ImH search plan,
99 % of improvement 377 seconds (including preparation time)

Figure 8. Grid B: proposed search plans with 5 SRUs on a grid of 7 by 95 cells

using the MILP-Ex model, the MILP-Im model and the MILP-ImH model respectively. The distribution of the whereabouts of the object in this particular instance has two important centers of mass. The MILP-Ex model found the optimal solution after almost 15 minutes. We note that the solution of the MILP-Im model is close, qualitatively, to this particular optimal solution. Moreover, on this problem instance, the myopic heuristic (the first solution of MILP-ImH) allowed the solver to obtain a high quality solution faster when using the MILP-ImH model. This particular solution was generated at least 8 minutes (480 seconds) earlier than the optimal solution and its objective value lies within 1 % of the optimal.

Figure 9 shows the search plans obtained with 5 SRUs on grid D. The search plan of Figure 9a is the one returned by the myopic heuristic (the first solution of MILP-ImH). The search plans of Figures 9b and 9c are the best search plans found within 15 minutes (900 seconds) by the MILP-Im model and the MILP-ImH model respectively. Note that the MILP-Ex model did not produce any search plan on that problem instance before the 15 minutes time limit. Following a close examination of these search plans, we see that the search plan proposed by the MILP-ImH model closely resembles the solution of the myopic heuristic (the first solution of MILP-ImH). Nonetheless, the search plan of the MILP-ImH model is still an improvement over the search plan proposed by the myopic heuristic. One particularity of this problem instance is the distribution of the whereabouts which has a circular shape centered on the last known position of the search object. The objective value of the best search plan found within 15 minutes, obtained after 324 seconds by MILP-ImH model corresponds to an improvement of 100 % since it is the best known



(a) Myopic heuristic search plan, 99 % of improvement after 23 seconds

(b) MILP-Im search plan, 98 % of improvement after 990 seconds (including preparation time)

(c) MILP-ImH search plan, 100 % of improvement after 324 seconds (including preparation time)

Figure 9. Grid D: proposed search plans with 5 SRUs on a grid of 47 by 49 cells

solution. Although the MILP-Im model achieved only an improvement of 98 % within 15 minutes, that particular solution was found after approximately 15 minutes (990 seconds). That is, the MILP-Im model found a solution within 2 % of the best-known solution after more than twice the time required (324 seconds) by the MILP-ImH model to find the best-known solution (100 %).

CONCLUSION

In this paper, we have presented a novel model based on mixed-integer linear programming to solve the search planning problem of allocating multiple search resources in response to a Search and Rescue incident. The algorithms developed are meant to be implemented in a decision support system for search mission coordinators who must plan and coordinate SAR response when time is a critical factor. Our model proposes search plans that assign search aircraft to non-overlapping rectangular search areas in such a way to maximize the probability of success while taking into account operational constraints. We compared two versions of our model, with and without a startup heuristic, to an older existing model proposed by Discenza 1978, using problem instances of realistic size. We showed that we are able to generate, in a reasonable time, operationally feasible plans for searches conducted in open and vast spaces. One particularly interesting result is the ability of our myopic heuristic to quickly generate quite a good search plan as a first solution, albeit not an optimal one. This is valuable since it quickly provides the search mission coordinator with an initial plan that could be improved upon while resources are being tasked or other preparatory activities are conducted. The work presented here served as a basis for an ongoing contract to implement search planning optimization in a decision support tool. More experiments with more cases are planned to thoroughly evaluate performances and make final recommendations. Ultimately, as our models get implemented in the Canadian Coast Guard operational decision support tool, we can expect an increase in the chances of finding survivors more quickly and in more lives being saved.

ACKNOWLEDGMENTS

The project was funded (in alphabetical order) by the Canadian organization for Mathematics of Information Technology and Complex Systems (MITACS), by Fonds de recherche du Québec – Nature et technologies (FRQNT), by Fonds de soutien à la recherche de FSA-ULaval, and by the Natural Sciences and Engineering Research Council of Canada (NSERC).

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Using Volunteers for Emergency Response in Rural Areas – Network Collaboration Factors and IT support in the Case of Enhanced Neighbors

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ABSTRACT

In public services, there is a trend to increasingly utilize collaborations with non-professional volunteers for certain tasks, one example being emergency response. In many of these collaborations, information technology (IT) is an essential tool, and inadequate IT support can have far-reaching consequences—including even the loss of lives. Since a volunteer is a different type of actor, and may have different technical requirements, compared to professionals, there is a need to explore how collaborations between professionals and volunteers can be successfully developed. This paper is based on a case study of the Enhanced Neighbor project, which uses volunteers as first responders in emergency response. The study highlights important factors to consider when involving volunteers, including how IT can foster the collaboration, and the volunteers' needs for IT support.

Keywords

Emergency response, IT support, volunteers, policy network collaboration.

INTRODUCTION

In contemporary society, there is a rising demand for increased flexibility, efficiency, and quality in public services. This, in combination with increasing societal challenges has affected the way the public sector is organized, with more responsibilities shared between different actors, who cooperate to deliver services (Agranoff and McGuire, 2010; Wankhade and Murphy, 2012). The way different actors collaborate within for example the area of emergency management can be explained through *policy networks* where social interactions between inter-dependent actors form a network with the purpose to gain more effective public services (Kickert et al., 1997). The collaboration form is sometimes seen as a necessary process in order to adjust to changing conditions and be able to reach innovative and flexible solutions in public sector (Alter and Hage, 1993). In the specific area of crisis management and emergency response, research has highlighted the potential of using volunteers as first responders, since they might be close to the incident site, and can arrive before professional response (Jack, 2005; Linders, 2012; Venema et al., 2010; Whittaker 2015). Specific methods for integrating this type of actor into emergency response have also been studied. Jaeger et al., (2007), for example, present the concept of "emergency community grids," where local authorities provide mobile technologies, e-services and information systems that volunteers can use to support others during a disaster.

In Swedish emergency response there are currently several emerging policy network collaboration forms. Examples include professions such as security guards, home care personnel, taxi drivers, and caretakers sharing certain tasks and equipment with the municipal fire and rescue services and emergency medical services; the increasing involvement of non-profit organizations; and, last but not least, citizens engaging as volunteers, for example in sparsely populated areas. Research stress that more knowledge of the actors' needs is required in order to further develop these collaborations and provide improved support. Examples of areas for further exploration include investigating in which type of emergency the volunteers can participate, and to identify needed tasks and responsibilities, skills, training, and organizational structures (Alexander, 2010; Havlik et al., 2016; Pardess, 2008; Schmeltz et al., 2011; Weinholt and Andersson Granberg, 2015; Yousefi Mojir and Pilemalm, 2016). These studies, however, mainly concern volunteers who are professionals engaging in inter-organizational collaborations or spontaneous voluntarism.

Previous research on citizen volunteer engagement (e.g., Diaz et al., 2016; Kawasaki et al., 2013; Ludwig et al., 2015; Palen et al., 2010; Ringh et al., 2011; Romano et al., 2014), thus mainly looks at spontaneous voluntarism in terms of large groups of citizens and/or from the professional response organizations' perspective. It does not specifically explore the needs of volunteers with an end-user, participatory focus. Those practical studies that exist are usually from a crowdsourcing perspective with ad-hoc organization where the volunteers responding could be almost anyone (Harrison-Paul et al., 2006; Howe, 2008; Ringh et al., 2011). In this study, we address this perceived knowledge gap by exploring important factors to consider when involving volunteers as first responders in the establishment of pre-planned, long-term, day-to-day emergency response, including the need for information technology (IT support). We achieve this by analyzing an on-going collaboration between Swedish municipal rescue services and volunteers, actively involving the volunteers as end-users. More specifically, our *research objectives* include:

- identifying collaboration related challenges and needs, such as training, equipment, communication, and IT.
- suggesting some solutions to the identified needs.

The study was carried out within the Swedish Emergency Response System (ERS), defined here as the organizations, personnel, methods, equipment and IT involved in carrying out rescue operations. The specific case studied is the Enhanced Neighbors project where volunteers collaborate with the municipal rescue services long-term to provide help with day-to-day emergencies. To increase the transferability of our findings, we have applied an analytical framework using general theories of policy networks and IT support to frame and support the analysis. As such, the results may be transferable to other actors within emergency management, or even large scale emergencies such as vast forest fires (e.g. regarding recourses and needs), and may also be relevant to other areas in the public sector and a wider IT audience.

METHODS

In this section, we provide an explanation of the study setting and the research approach, followed by a description of the empirical data collection and the analysis methods applied.

Case Study

The study is an exploratory case study (Myers, 2009) of the Enhanced Neighbors project, which involves volunteers as first responders to emergency incidents in rural areas. The response context is dynamic whereas different volunteers respond to different emergencies, preconditions changes over time and new needs arise.

At the time of the study, five remote villages in the county of Medelpad participated in the project. Medelpad is a sparsely populated area in the northern part of Sweden consisting of three municipalities, with a population of approximately 125,000 and an area of 7,000 square meters. The rescue services provides basic training in cardiac resuscitation, first aid and extinguishing small fires, and related practical exercises to the volunteers. The volunteers then receive text messages on their personal cellphones when there is an emergency in their village area, and are free to choose whether they want to act on the alert provided by SOS Alarm (the national alarm centre). If they decide to respond, they can provide assistance while waiting for the recue services, e.g. by keeping a victim's airway open, or extinguishing a small fire.

Data Collection

During approximately one year (2014-2015), we employed several different types of data collection methods, including interviews, focus groups, document studies, a future workshop, and an exercise (Kensing and Halskov Madsen, 1991; Myers, 2009). Our goal was to use different data sources to achieve the triangulation and multiple perspectives usually associated with the collective knowledge creation, enhanced understanding, and credibility of case study research (Flyvbjerg, 2006). Our goal was also to involve the volunteers actively and concretely. Several data collection methods, e.g. the focus groups, the future workshop and the exercise, foster dynamic and active user participation.

Interviews were performed with volunteers (three focus groups and one interview), the municipal rescue services and SOS Alarm (six interviews). In addition, a future workshop specifically aimed to enable active user participation was arranged with 11 participants (three rescue service professionals and eight volunteers) to discuss the volunteers' situation and needs for improvements. The interviews and workshop were documented with written notes, and audiotaped for further transcription and analysis. An exercise involving a simulated single-car traffic accident with three injured—one cardiac arrest victim, one person trapped in the wreck, and one person in chock with minor injuries—was also performed in one of the villages. Volunteers, as well as professional fire and rescue services, were dispatched to the site. The exercise was filmed, audiotaped, and observed by two researchers on site and one at the emergency center. After the exercise, an after action review was held with volunteers, the fire and rescue services, and the call operator/dispatcher from SOS Alarm.

Data Analysis—ICT collaboration through a Policy Network Framework

Our study focuses on a collaboration between rescue services and volunteers aiming to improve the local emergency response – i.e. a policy network to improve the local safety. The emphasis is on what the volunteers need in order to be successfully integrated into the response operations.

Initially, we read through all the transcribed scripts and notes from the data collection, and from there, using thematic analysis, implicit and explicit ideas and patterns were identified (Guest et al., 2012). These were then structured with the support of a conceptual analytical framework containing different factors of policy networks. The framework emanates from collective action theory, with reference to the institutional analysis and framework development (Carlsson, 2000). It has previously been tested and applied to collaboration in local crisis management (Palm and Ramsell, 2007). For this study, we adapted the framework by removing two factors that were incompatible with our research, and another that overlapped with other factors within the study context. Also, the factor of IT support, was added to the framework. Finally, challenges and needs associated with each factor, as found in the data, were identified, and solutions were suggested. The complete analytical framework is composed of four factors:

- Problem Definition
    - Policy networks emerge and are shaped depending on the definition of the policy problem in question. In our case study, this means how the project was defined and how the scope of the collaboration is described and perceived.
- Contextual Factors
    - Policy networks emerge and are shaped differently in different contexts. This include how contextual factors such as demographics, resources, skills, and social relations influence the development of the collaboration between the actors, e.g. the rescue services and the volunteers.
- Formal and Social control
    - Networks are subject to both social control, emerging from the processes of interaction between the actors, and formal control, which can stem from regulations, agreements and laws. Here, this involves investigating which kind of control factors that affect the volunteers' engagement, and if these can influence the development of the collaboration.
- IT Support
    - IT is an essential tool for collaboration between actors, since it facilitates information and knowledge handling in networks (Margetts, 2005). As such, IT can foster collaboration. Especially interesting for our study are the IT needs of the volunteers, and if IT plays a facilitating role in the collaboration.

An overview of the framework is shown in Figure 1.

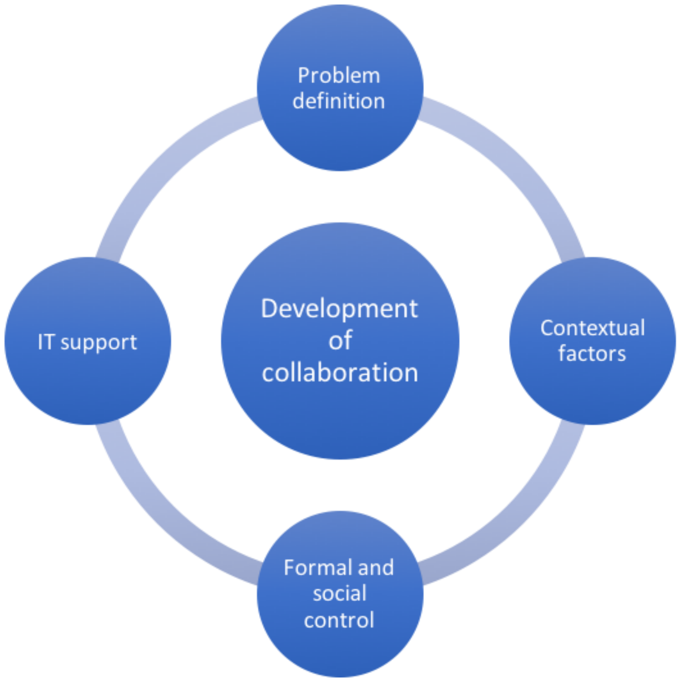

Figure 1. Adapted analytical framework based on Carlsson (2000)

RESULTS

In this section, we present and analyze identified important factors to consider when involving volunteers as first responders. Each sub-section starts with a general analysis of how the project has managed each factor in the analytical framework. Thereafter the challenges, needs and solutions relating to respective factor are analyzed.

Problem Definition

Both rescue service officials and volunteers involved in the Enhanced Neighbors project defined the problem in the same way: geographical distances made emergency response times unacceptably long. Before the rescue service arrived, residents' lives could be at stake, and serious material damage might occur. Without the ability to employ more staff and expand their own organization (due to scarce economic resources), the rescue service needed external (free of charge) support: volunteers. The volunteers, on their part, were clearly aware that, despite Swedish legislation requiring fire and rescue services to deliver equivalent service, this was difficult in their villages. By collaborating with the rescue services, they could increase safety for themselves and their neighbors. The collaboration between the rescue service and the volunteers seemed to be clearly defined. When volunteers were asked what was expected of them, a common reply was "To arrive quickly at the emergency site and do whatever you can" (volunteer, focus group). Some respondents, however, expressed concern that this collaboration might result in even less support from the rescue services:

> *If there is high [volunteer] engagement in one village, the rescue service might prioritize another [village] if there are several emergencies at the same time… (volunteer, focus group)*

To define the assignment, the rescue service compiled a list of emergencies that volunteers could be dispatched to: heart failures, traffic accidents, drownings, and selected fires. All these incidents are urgent and require an immediate response, and it is also possible to provide initial assistance without professional skills in medicine or rescue.

Challenges—Redefining the Assignment and Addressing the Lack of Practical Experience

One challenge relating to the understanding of the assignment was that, at the time of the study, many of the volunteers had not yet responded to a real emergency, since these seldom occur in small villages in sparsely populated areas. They understood the overall assignment, but several had no real experience of performing concrete emergency-response-related tasks. Even though the volunteers themselves said that their responsibilities in potential incidents were relatively clear, in the course of the study it became evident that several central issues were still undefined. It was not clear for example, if the volunteers were supposed to respond to an emergency by themselves: "No, of course you don't want to go by yourself; you need to have someone else with you…" (volunteer, focus group) and there was no structured way of knowing anyone else was going.

To compensate for the volunteers' lack of experience, practical exercises relating to the list of emergencies were conducted jointly with the ambulance and rescue services, e.g. carrying out cardiac resuscitation and extinguish small fires. Challenges observed during the exercise in the case study included uncertainty on the part of the volunteers in terms of the distribution of tasks, such as when and how to hand the operation over to the rescue services, inability to know the number and identities of volunteers responding to the alarm, and the lack of information regarding when the rescue services would arrive. Furthermore, there was no way of knowing who had done what at an emergency site, resulting in the risk that some tasks were left undone, while other tasks were repeated. All of this created uncertainty for the volunteers.

Needs and Solutions—Exercises and Feedback

Hands-on exercises: The "hands-on" exercise performed as part of the study (i.e. the simulated car accident) proved useful in clarifying concrete tasks and responsibilities. The volunteers wanted to have more exercises. The rescue services, on the other hand, struggling even to provide basic training and education, hopes that the volunteer groups gradually will become more self-sufficient. A possible solution might be for already-educated volunteers to become responsible for conducting small drills in between the exercises run by the rescue services, in order to maintain the volunteers' preparation levels.

Feedback/debriefing: The volunteer respondents also requested procedures for post-emergency feedback and debriefing in order to clarify tasks and identify further needs. Some volunteers also felt that it was vital to talk to someone, to help them feel emotionally and psychologically ready to respond to future emergencies.

Contextual Factors

The structural context is the Swedish ERS while the physical context is Medelpad county. Among the volunteers, there are many long relationships: several have known each other for more than 20 years, and spouses and parents with their adult children also participate. Some of the volunteers have ERS related skills, and feel they can contribute to increasing the village's safety. In addition, several of the volunteers are middle aged or older, and recognize their own vulnerability:

> *Because of our age, we belong to a risk category, and that also contributed to our motivation to become volunteers (volunteer, focus group)*

For some volunteers, the health and property of the village's inhabitants seemed to be more important than helping strangers. They were not very interested in responding to traffic accidents on the highway, for example, even if they could reach the accident site faster than the rescue services. This points to another reason for volunteer engagement: contributing to the village's "survival." Public services in many villages have decayed. The volunteers perceive the Enhanced Neighbors project as a positive development, with the installation of an automatic external defibrillator (AED) in the village being one concrete example.

In terms of the volunteer group context, some groups were created in connection with the project, while others were pre-existing, including voluntary fire brigades and part-time firefighters. Other volunteers had been engaged in different sorts of village communities involving both social activities and safety activities, such as fire prevention. An early project strategy was to recruit, wherever possible, already-established groups of volunteers in order to facilitate the collaboration.

Challenges—Resources and Inter-Agency Collaboration

The contextual factors have also generated specific challenges. Since many of the volunteers work during the day, for example, the rescue services had to provide education and practical exercises mainly on evenings and weekends. Both the rescue services manager and staff reported that working in their spare-time was stressful. The amount of residents interested in volunteering was also higher than anticipated, and even though it was commonly agreed that it would be better to start with a limited group, there was frustration within the rescue services when the development and expansion was hindered by a lack of resources. "The thing is, we started this project basically within the existing budget" (interview with rescue manager responsible for the project).

Needs and Solutions—Personnel Resources

Adding personnel resources: To create a feasible work environment for the rescue service staff, additional employees need to be allocated to this and similar projects. The rescue service had already realized this when we conducted our study, but there were delays due to organizational restraints.

Formal and Social Control

There are not many formal agreements between the actors. SOS Alarm and the rescue services signed an agreement for the alarm company to receive a fixed amount of money for sending emergency response alerts to the volunteers. Another agreement involves SOS Alarm to develop and adapt their current decision support system for dynamic resource allocation for incoming emergencies, and here the rescue services wish to integrate volunteers as resources. There is no formal agreement, however, between the rescue services and the volunteers. The volunteers have no obligation to respond to an emergency. Despite this, according to the rescue services, at least one, and usually several volunteers have responded to all emergencies to date, and have arrived swiftly, reaching the emergency sites before the rescue services: “The first alert I received, I arrived 45 seconds later at the site—it was just across the street” (volunteer, focus group).

Challenges—Volunteer Safety and Degree of Collaboration Structure

One challenge generated by the collaboration is the voluntarism itself: Since volunteers are free to decide whether or not they will respond to an alert, the rescue service cannot rely on them—they are only a complement[1]. According to the rescue services, this is within the core idea behind Enhanced Neighbors. As one of the employees explained:

> *... an ordinary private person with no special obligations or rights, receives information about an accident nearby, and can decide whether or not to go and help (rescue service professional, interview).*

This definition of the volunteers is problematic, since Swedish law on this matter is unclear, and legal protection for the volunteers is insufficient. If a volunteer is injured during a response operation, or cause damage to victims, material or property, he or she has no specific insurance coverage. When asked about current regulations and insurance, the rescue service project manager only mentioned the volunteers’ own personal home insurance. The rescue services had thus not verified if volunteers have appropriate insurance. As for the volunteers themselves, the question of insurance seems to be a non-issue; it was the researchers who brought it up during the interviews.

In addition, the volunteers are not financially compensated for any expenses they may incur in relation to a rescue operation and need to make their own investments as to basic equipment (ranging from defibrillators to first aid kits to blankets). Initially, they seemed untroubled by this. But as the collaboration lengthened and their expenses increased, they requested some sort of economic support. One of the defibrillator components must be exchanged after each use, for example, and costs approximately 200 euros. Overall, the volunteers want the collaboration to be more structured. The rescue services, however, wants it to remain as informal as possible, with the volunteer groups eventually evolving into more self-sufficient entities. Building up an administrative structure for the collaboration that requires resources to maintain is not an option for the rescue services.

Another challenge relates to privacy and ethical issues. The Swedish personal data act stipulates that names of accident victims cannot be provided in the SMS alerts or via any IT solution the volunteers can access. As a result, volunteers use the Internet to find out who lives at the address they receive in the SMS alert. Even if this information were openly available, and conformed to the regulations, however, it may pose ethical dilemmas, since people may not be willing to help, or receive help from, someone they have had differences with in the past. The other way around, respondents in one focus group mentioned that they were more willing to respond to an emergency if they knew the victim.

Needs and Solutions—Availability Issues, Insurance, Basic Equipment and Ethical Aspects

Dealing with uncertain availability: As there is currently no way of knowing in advance which of the volunteers that are actually available any technical support developed needs to be accompanied by a strategy that addresses

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[1] In Sweden there is no legislation for a general obligation to assist a person in distress, e.g. see SOU [Swedish official investigation] 2011:16, Allmän skyldighet att hjälpa nödställda? [General obligation to assist distressed?]

this uncertainty. For example, such a strategy might be to confirm which and how many volunteers that have responded to the emergency alert and dispatch additional volunteers if those first alerted acknowledge that they will not go.

Insurance: A juridical investigation conducted in connection with our study clearly showed that volunteers do not currently have sufficient legal protection. The rescue services and/or municipalities clearly need to provide collective insurance for the volunteers, possibly with support from small local insurance companies.

Need for basic equipment: Above all the exercise demonstrated a clear need to invest in medical equipment, such as first aid kits and blankets, and practical equipment, such as flashlights and reflective vests. The question is who should pay; the volunteers or the rescue services? Either solution has drawbacks as to structure versus informality. The rescue service may need to support the volunteers to some extent in order to keep them engaged.

Privacy and ethical aspects: Even if formal regulations concerning privacy remain in place, and ethical guidelines concerning whom to help—due to the voluntary character of the project—are difficult to define, discussions with volunteers about the ethical dilemmas that may arise are needed. These could be incorporated into the volunteer education and practical exercises.

IT Support

The current IT solution is a very basic system in which volunteers receive an alert in the form of a simple text message to their personal cellphones (see Figure 2). There is no current integration with the national digital emergency communication system, Rakel, nor with SOS Alarm's decision support system for dynamic resource allocation, and therefore limited communication and no positioning functionality.

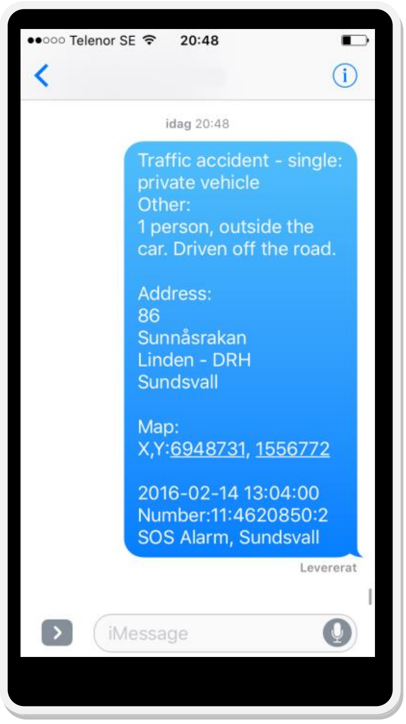

Figure 2. Example of an SMS alert, translated from Swedish

Challenges—Absence of Important Functions and One-Way Communication

All actors—rescue services and SOS Alarm employees, as well as volunteers—agreed that using SMS technology, while not an optimal solution, is the only solution available at present. However, its functions are much limited, presenting many obstacles to communicating and collaborating with the rescue services. Above all, SMS is a one-way communication solution. Volunteers are unable to indicate if they will respond to the emergency, nor can they communicate with the ambulance or rescue services either en route or on site. The only option available to them is calling the 112 national emergency number, a situation that both volunteers and the rescue services viewed as problematic.

In addition, the lack of positioning functionality clearly affects the viability of the current SMS solution. At present, volunteers receive an alert regardless of their current location—even, for example, if they are on holiday in another country. Conversely, a volunteer might be in another village—visiting friends, for example—where an accident occurs, and not receive an alert since he or she is not registered in that particular village. There is also the risk that a volunteer will not immediately observe an emergency-related SMS, since there is no specific signal indicating an emergency.

Although the rescue services had been promised that the volunteers would be integrated into the dynamic resource allocation system soon, there were delays in development from the supplier, SOS Alarm. In order to provide an interim solution, the rescue services tried to find another supplier, and located a company within their budget. This supplier, however, was not allowed to take on the rescue services as a customer, since company policy allowed them to take on only private, non-government clients. As such, the rescue services and volunteers are forced to wait for SOS Alarm to finish the integration work. This also relates to the formal control factor, since the rescue service's status as a governmental organization restricted them to one supplier, delaying the development of IT support, and hindering the collaboration between the rescue services and volunteers.

Needs and Solutions—Two Way Communication and other Necessary Functions

Expanded SMS communication functions: Many of the communication challenges can be addressed by simply improving the SMS functionality, including the ability to acknowledge receipt of the alerts and communicate with the rescue services en route and at the emergency site. The volunteers also proposed having access to a direct telephone number to the rescue services, though current regulations need to be studied to see if this is permitted. More structured forms for communication among the volunteers themselves (to know who is on the way and who brings the relevant equipment) were also requested and can be sustained by various chat functions.

Technical integration with professional response organization's resource management system: Technical integration with SOS Alarms' decision support system for dynamic resource allocation would make it possible to manage the volunteers as professional resources, including positioning, dispatching and communication. This would e.g. solve the problem of not knowing how many, or who, that responds to an incident.

GPS positioning: The ability to geographically locate volunteers is clearly needed, so that only those volunteers who are actually near the emergency site are alerted. As mentioned above, this, however, requires integration with the professional resource management system. Meanwhile, the volunteers want to be given directions to the incident site, since sometimes it is difficult to find the way. A link to Google Maps with driving instructions to the emergency site could easily be integrated into the SMS.

Mobile checklists: The volunteers request mobile checklists that include information such as telephone numbers, and what equipment to bring when responding to different types of emergencies. An application providing instructions for CPR and first aid was also suggested, however the volunteers underlined this should not replace direct communication with the rescue and ambulance services.

The challenges and solutions connected to each factor important for development of collaboration are summarized in Table 1 below.

ANALYSIS

In this study, we set out to explore collaboration and needs for IT support when establishing long-term policy networks of pre-planned voluntary engagement in day-to-day emergency response. Even though IT needs and requirements thus were part of our focus, the results indicate that these are not substantially different comparing to those of professional end-users. Surely, the volunteers may have some specific needs such as checklists and SMS group chats compared to the professionals. However, the most prominent critical factors identified in the Enhanced Neighbors project concerns the social and organizational context of the technical solutions. Even though the project had been in progress for half a year, and some volunteers had been dispatched to real emergencies when we started the study, they did not have insurance, basic equipment or routines for feedback. In addition, the rescue services had to adjust to the volunteers' availability to perform education and training, and do this during evenings, i.e. they had to have a dynamic and flexible organization. There were also uncertainties about tasks, responsibilities, regulations, and legal issues, as well as the challenge to educate the large amount of volunteers who signed up (in order to maintain interest), in combination with finite resources.

Another critical factor was the need to develop emergency strategies handling uncertainty of volunteer's ability and willingness to responde. This may be compared to professional response organizations whose personnel who will always respond, if dispatched. Not even the challenge of integrating the volunteers in the rescue services' IT-system were actually a technical issue; it was rather about organizational boundaries, regulations and administrative hindrances. Consequently, the technical solution became very simple and low tech and did not meet the volunteers IT needs. As such, the current IT solution can be said to be an important pre-requisite for the collaboration, but not actually fostering it.

Factor	***Result***	
	Challenges	***Needs and Solutions***
Problem Definition	- To define and continuously redefine the assignment, as well as clarify the expectations, for volunteers in a dynamic context. - Lack of experience from real emergencies.	- Practical hands-on exercises. - Routine for feedback/debriefing.
Contextual Factors	- Contextual hindrances e.g. organizational borders. - Stressful for the rescue service to devote spare time. - Lack of staff resources to enhance the development.	- Additional employees to be allocated.
Formal and Social Control	- Lack of agreements between the parties; the rescue service cannot rely on the volunteers to respond. - Insufficient insurance coverage of the volunteers. - No financial compensation for expenses, e.g. equipment. - Open but sensitive personal information used by the volunteers.	- Strategy dealing with uncertain availability - Collective insurance for the volunteers. - Economic support to the volunteers to keep them engaged. - Discussion about privacy and ethical aspects.
IT Support	- Difficult to develop and integrate adapted IT-support. - Limitations in the current IT-system functionality. - One-way communication–volunteers cannot communicate/ask questions to the rescue services during a response	- Acknowledge receipt of the alerts; enable two-way communication between volunteers and rescue services. - Integration with the decision support system for dynamic resource allocation. - GPS functionality; link to Google Maps; mobile checklists.

Table 1. Development of collaboration – summary of important factors structured by challenges, needs and suggested solutions

CONCLUSION AND FUTURE WORK

In contemporary society, reduced professional resources in combination with increasing societal challenges have led to an increasing trend of including citizens in public services—for example as first responders in emergency response (Diaz et al., 2016; Jaeger et al., 2007; Pilemalm et al., 2016). Even if the challenges and needs for improvement regarding such involvement have been in focus in this study, the Enhanced Neighbors project is still deemed a successful example. Here, actors other than public actually perform functions–respond to alarms and carry out tasks at the emergency site–to contribute to higher quality in public services. This form of self-government can, if carried out successfully, increase the safety of both the volunteers and their neighbors (Bekkers et al., 2007).

However, pre-planned, long-term and structured collaboration with volunteers also bring additional substantial intricate issues compared to other emerging forms of collaboration in emergency response, e.g., inter-organizational among professionals and cross-sector collaboration among professionals and semi-professionals. The reported challenges of identifying tasks and responsibilities, skills and organizational structures in such settings involving e.g. guard companies and home care personnel (e.g. Weinholt and Andersson Granberg, 2015; Yousefi Mojir and Pilemalm, 2016), become even more complex in the case of volunteers. This is much due to that they do not have any organizational belonging and no formal employer–they simply have no basic structure for the collaboration. It also results in entirely new challenges, as to alarm strategies, regulations and legal issues and IT integration. Also, the volunteer long-term establishment of policy network collaboration requires other solutions in the above aspects as compared to crisis management relying on crowdsourcing and ad-hoc organization. On the other hand, some of the results, above all the concept of using (the same) trained and pre-equipped volunteers both for day-to-day emergencies and in large-scale crises seem applicable, and also the need for two-way communication (Havlik et al., 2016).

When citizen volunteers act as first responders, they thus need to be provided access to, and be integrated in, the public organizations' information systems and IT tools, such as their decision support systems. This means that they should be actively involved in development of these same systems. As part of this study, we set out to explore whether the IT support used could be seen as fostering the collaboration. This was not really the case. Actually, even though the project had been running for some time, many concrete needs (IT and other) where not identified until active user participation was enabled. The importance–and difficulties–of involving the end-user has been emphasized many times in earlier research (e.g. Holgersson and Karlsson, 2014). It has also been argued that the overall complexity and difficulties associated with active user participation increase in the case of using volunteers in public services, including emergency response (Pilemalm et al., 2016), requiring further study. In conclusion, the concept of establishing long-term and regular involvement of volunteers in day-to-day emergency response thus seems to generate specific research issues to be dealt with, regarding both the policy networks themselves and the associated IT support. Within the context of Enhanced Neighbors, we will study the integration of the volunteers into the professional emergency resource management system further. We will also apply drawn conclusions and experience from the project to other similar projects in Sweden, but in urban settings and socio-economic vulnerable areas.

ACKNOWLEDGEMENTS

This study was made possible by joint financing from the Swedish Civil Contingencies Agency (MSB) and SOS Alarm.

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On the use of automated planning for crisis management

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ABSTRACT

Automated planning is a domain of Artificial Intelligence which aims to study the deliberation process used to choose and organize actions by anticipating their expected outcomes. In this paper, we discuss the use of automated planning techniques in crisis management contexts. To begin with, the crisis management planning problem is formalized in light of the conceptual model for automated planning. In addition, we describe the conceptual scheme of an information system generating action plans in order to support decision-makers in crisis management. Finally, a proof of concept implementation of the aforementioned system is presented.

Keywords

Crisis management, automated planning, collaborative plan, multicriteria decision analysis, ChoPlan

INTRODUCTION

A *crisis* (or critical situation) can be defined as "a situation with long-term consequences due to an event that has caused extensive damages and losses resulting in an interruption of one or more critical activities within some part of the world" (CCA 2014). Such situations may, for instance, result from natural disasters (tsunamis, earthquakes, floods. . .), industrial accidents (e.g. an explosion of a production facility) or from malevolent acts (terrorist attacks for instance). Managing critical situations still represents a major challenge for our society. Indeed, between 2006 and 2015, crisis were responsible for approximately 70,000 deaths per year according to the last statistical review of the international Emergency Event Database (Glasser and Guha-Sapir 2016). Most of the practitioners (see for example (Altay and Green 2006)) describe the life cycle of crisis management using four phases: *prevention*, *preparation*, *response* and *recovery*. This study mainly focuses on the response phase.

When a crisis occurs, many organizations are mobilized to respond. The term *organization* is used here in its broadest meaning ; it may refer to state emergency services such as fire department or police as well as companies or associations. The management of the crisis response is generally charged to a so called *crisis cell* composed of various stakeholders: one or more decision-makers assisted by relevant actors and experts in light of the situation. The mission of the crisis managers is delicate since they have to coordinate the collective work of many organizations in a stressful and time-constrained environment. In most cases, involved organizations are both heterogeneous (at cultural, functional and technological levels) and poorly, if at all, trained to work together in the emergency context of the crisis. This inevitably leads to collaboration issues (imperfect definition of the goals to achieve, incomplete information sharing, poor coordination of actors. . .) that limit the efficiency of the response. These problems have been highlighted by many feedbacks from past crises (Van De Walle and Turoff 2007; Treurniet et al. 2012) showing that maturity of the coordination between stakeholders is a limiting factor in crisis management.

To address these collaboration issues, preventive contingency plans are generally prepared before critical situations arise. Unfortunately, as they are generated when the operational context of the collaboration is not entirely known and because real crisis situations may diverge rapidly from planned ones, these plans are often imperfect. Dwight D. Eisenhower has said in this regard that "Plans are worthless, but planning is everything" (Eisenhower 1957). Through this statement, the military strategist emphasize the necessity for a plan to fully fit into the operational context justifying its creation. In order to avoid the aforementioned limitations, this study only focuses on action plans that are produced once the crisis event has occurred.

One should note that the crisis cell operate at a strategic level. As a consequence, *collaborative plans* produced by its members are singular in some regards. They involve many organizations and focus less on the precise description of the actions to execute (which belong in the expertise area of the responders) rather than on the orchestration of these actions. Indeed, according to the principle of subsidiarity, decision-makers can order to involved partners what to do and when to do it but they never advise them on the way these tasks should be performed. Besides, planning activities performed by the members of the crisis cell are the only ones to be considered in this study. Other planning approaches for crisis management (for instance, planning to optimize victim evacuation by taking account of the road traffic (Aligne and Savéant 2011)), although independently interesting, are considered as complementary to our approach but are not discussed further.

Automated planning is a domain of Artificial Intelligence which studies the deliberation process that chooses and organizes a set of actions according to their expected outcomes. In this paper, we discuss the use of automated planning techniques in order to support the planning activities of the crisis cell's members. First, a brief overview of automated planning and its conceptual model is given. The assumptions of this conceptual model are then analyzed in the context of critical situations as we present what we believe is the correct way to model the crisis management planning problem. This problem encompass two distinct problematics amongst which only the first one is studied. Indeed, the third section focuses on this problematic by describing the core features that an information system generating plans in order to support the crisis managers should possess. Next, a proof of concept implementation of such a system is presented. Finally, a concluding section sums up these results and suggests some perspectives.

AUTOMATED PLANNING OVERVIEW

Automated planning addresses the problem of finding a sequence of actions to execute on a system Σ in order to achieve a specified goal state from a given initial state. In its broadest meaning, the planning activity encompasses both the plan elaboration as well as its execution. A conceptual model for planning has been proposed in the reference textbook *Automated Planning*: *Theory and Practice* (Ghallab et al. 2004). It is based on the interactions of three components: a planner, a controller and a system Σ (cf. figure 1).

1. The *planner* generates an action plan based on the description of the system Σ, its initial state and the objectives to achieve ;
2. The *controller* executes the plan generated by the planner thereby producing actions on the system. To do so, it relies on information (possibly incomplete) from the current state of the system ;
3. The *system* Σ evolves in response to actions performed by the controller or external events that may occur.

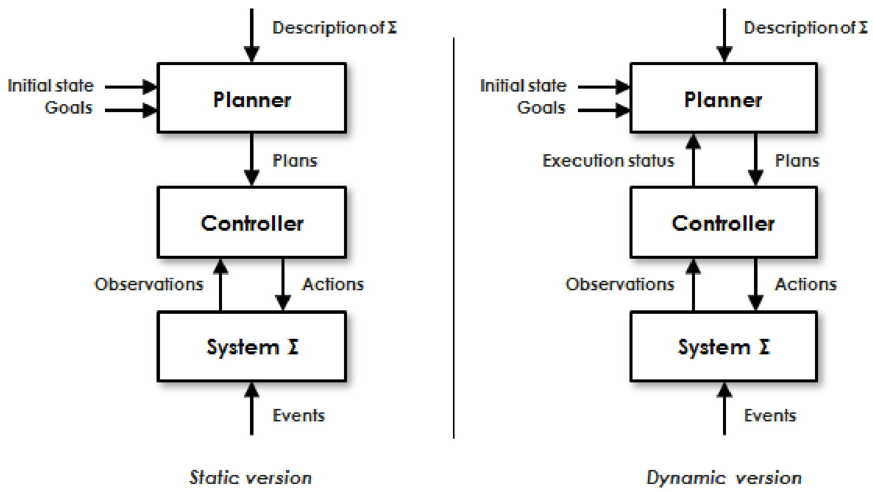

Figure 1. Conceptual model for planning (Ghallab et al. 2004)

The controller is usually assumed to be robust enough to handle the differences that may exist between the real world and its model. However, if this assumption is not acceptable, the controller may return an execution status to the planner allowing the latter to produce a new plan whenever the observed situation and the expected one diverge. In this case, the term *dynamic planning* is used to denote that the construction of the plan and its execution become closely linked (cf. feedback loop on the right part of figure 1).

Since planning is concerned with choosing and organizing actions in order to modify the state of a system, a model to specify and describe the dynamic evolution of systems is required. The *state-transition system* model (Dean and Wellman 1991) is generally used to this end. Formally, a state-transition system is a 4-tuple $\Sigma = (S, A, E, \gamma)$, where :

- S is a finite or recursively enumerable set of states ;
- A is a finite or recursively enumerable set of actions ;
- E is a finite or recursively enumerable set of events ;
- $\gamma : S \times A \times E \rightarrow \mathfrak{P}(S)$ is a state-transition function (with $\mathfrak{P}(S)$ denoting the power set of S).

Modelling Σ as a state-transition system is equivalent to describing it by its state $s \in S$. As a consequence, an evolution of the system Σ corresponds to a state transition $s \rightarrow s'$. In the conceptual model for planning, the transition from a state s to a state s' is represented by the execution of an action/event pair (a, e) in s. The neutral action α and the neutral event ϵ are introduced in order to describe transitions caused only by actions or caused only by events. In such cases, notations $\gamma(s, a)$ and $\gamma(s, e)$ are used in place of $\gamma(s, a, \epsilon)$ and $\gamma(s, \alpha, e)$. One should note that although actions and events both contribute to the system evolution, their semantics differ. Actions are controlled by the people in charge of the plan execution whereas events are transitions that are beyond their control. The latter can be caused by the internal dynamic of the system or the evolution of its environment.

The function γ indicates the state s' towards which the system Σ may evolve from state s in response to an action a, an event e or an action/event pair (a, e). Thus, the size of the set returned by $\gamma(s, a)$, which is denoted as $|\gamma(s, a)|$, provides several information regarding the execution of a in s. If $|\gamma(s, a)| > 0$, the action a is said to be applicable in s since the system Σ can transition towards at least one state s' whenever a is executed in s. In addition, if $|\gamma(s, a)| \leq 1$, the execution of a in s is said to be deterministic. Indeed, if the action a is executed in s, the system Σ can only transition to a single state s'.

Furthermore, the conceptual model for planning (Ghallab et al. 2004) introduces eight assumptions that are used to characterize the different classes of planning problems.

Assumption A1 (Finite Σ). The system Σ has a finite set of states.

Assumption A2 (Fully Observable Σ). The state of the system Σ is fully observable. Therefore, the observations used by the controller are all perfect.

Assumption A3 (Deterministic Σ). The system Σ is deterministic if for every state s, every action a and every event e, $|\gamma(s, a, e)| \leq 1$. Thus, in response to an action/event pair (a, e) applicable in s, the system Σ can only transition towards a single state s'.

Assumption A4 (Static Σ). The system Σ has no internal dynamics therefore the set of events E is empty.

Assumption A5 (Restricted Goals). One can only specify goals to achieve as properties of the final state of the system. As a consequence, a solution to a planning problem is any sequence of state transitions which leads to a final state $s \in S_G$ with S_G the set of states in which the objectives are verified.

Assumption A6 (Sequential Plans). Solution plans are represented by a finite sequence of linearly ordered actions thus there is no parallelism involved in them.

Assumption A7 (Implicit Time). Actions and events have no intrinsic duration and are considered as instantaneous state transitions.

Assumption A8 (Offline Planning). Dynamic planning mechanisms are not required.

The term *classical planning* refers to the class of problems obtained when all the assumptions of the conceptual model are considered simultaneously. Studying the classical planning problem is fundamental because most of the planning problems are defined by extending the latter ; like the crisis management planning problem presented in the next section for instance.

Classical Planning Problem (Ghallab et al. 2004). Given $\Sigma = (S, A, \gamma)$ a state-transition system, $s_0 \in S$ an initial state and $S_G \subseteq S$ the set of the states verifying the restricted goals G, find a sequence of actions $\langle a_1, \cdots, a_n \rangle$ corresponding to a sequence of states $\langle s_0, \cdots, s_n \rangle$ such that $s_1 = \gamma(s_0, a_1), \cdots, s_n = \gamma(s_{n-1}, a_n)$ and $s_n \in S_G$.

As the assumptions of the conceptual model are rather restrictive, some real world problems can not be modelled accurately by the classical planning problem. In such cases, one may consider other classes of problems by relaxing some of the aforementioned assumptions. These new classes of problems are harder to solve and constitute various subdomains of automated planning. For instance, the assumption A7 is relaxed in temporal planning while assumptions A1 and A5 are not considered in preference-based planning.

In the following section, assumptions of the conceptual model are analyzed in the context of crisis management. Doing so, we present what we believe is the correct way to model the crisis management planning problem.

AUTOMATED PLANNING FOR CRISIS MANAGEMENT

As mentioned in the introduction, dynamics of critical situations may be relatively unpredictable. As a consequence, assumption A8 has to be relaxed in the context of crisis management. Using a dynamic planning approach is more complex as it implies to monitor the crisis response in order to detect potential divergences between the actual situation and the expected one. If such a case occurs, the current plan must either be adapted or completely redesigned to take into account the novelty of the situation. On the other hand, other assumptions may be considered thanks to dynamic planning thus offering an interesting trade-off between the complexity of the planning problem to solve and the need to adjust the produced plan during its execution. Indeed, assumptions A2, A3 and A4, even if not unconditionally true in a crisis management context, may be considered as valid hypotheses given the possibility to restart the planning procedure if needed. Doing so, the system may be considered fully observable, deterministic and static. Nevertheless, replanning mechanisms will be triggered if a (previously unknown) relevant information becomes available, a responder action does not produce its expected outcome or if an external event significantly impacts the system environment.

Crisis management planning problems are rather different from traditional automated planning problems. They tend to be easier to solve than the latter as they are usually less combinatorial while being much harder to model. Indeed, it is quite difficult to represent the goals to achieve as determining the best strategy to efficiently handle the situation is generally crisis-specific and might be subject to debate amongst decision-makers. It results from these considerations that assumption A5 is too restrictive in a crisis management context. In order to fully capture decision-makers needs, extended goals and preferences (Gerevini and Long 2006) should be preferred in place of restricted goals. Goals are strong constraints that must be verified by the solutions of the problem whereas preferences are soft constraints that may not be verified in a solution plan. Extended goals encompass both *final state goals* (which correspond exactly to the restricted goals of assumption A5) and *trajectory goals* that formalize requirements on the sequences of actions characterizing the solution plans. For instance, they can be used to forbid transitions to specific states or to force the system to be in a particular state before another one. Similarly to objectives, preferences can represent conditions on the final state (*final state preferences*) or intermediate states (*trajectory preferences*) of the solution plans. In addition, they can also refer to any numeric variable (*numerical preferences*) defined in the problem. This gives them a rich expressive power since they can describe costs and risks to be minimized (logistic cost, response time. . .) as well as quantities to be maximized (some quality levels for example). When numerical preferences are used to describe the state of the system, it becomes impossible to consider assumption A1. Relaxing this assumption is mainly a technicality ; although it may affect employed automated planning techniques, it has no operational impact. Furthermore, in a crisis management context, one should consider the approach described in (Bidoux 2016) which use the Multi-Attribute Utility Theory formalism (Dyer 2005; Grabisch and Labreuche 2010) along with a Choquet integral (Choquet 1953) to represent the aforementioned preferences. It enforces commensurability between the considered preferences (trajectory and numerical preferences are not by default and are relatively hard to compare) which greatly simplifies both the modelling of the planning problem as well as the comparison of candidate solution plans. Moreover, this approach offers additional expressive power advantages as it allows decision-makers to aggregate several preferences together and to take into account interactions that may exist between the preferences.

Time is often a critical resource in a crisis management setting, where parallelizing responders actions whenever possible in order to optimize response efficiency is generally very important or even crucial. This indicates that assumption A6 of the conceptual model for planning is not suitable in such contexts. Parallelization can be performed either while planning (increasing the problem difficulty) or as a post-treatment once a solution plan is found. The latter approach may produce potentially suboptimal plans from a scheduling point of view but nonetheless constitutes an interesting trade-off in a crisis management context. In fact, a post-treatment may be sufficient to greatly improve the response efficiency because the solution plans are inherently highly parallelizable as they involve many organizations. Whether one should relax assumption A7 (by taking into account the duration required to execute plan's actions) is fairly debatable. Such a feature could be interesting as it may improve the efficiency of the response (from a scheduling perspective) or ensure that the produced plans are deployable in a given time frame. Nevertheless, using temporal planning techniques is not always feasible or even desirable in a crisis management setting. Indeed, it requires to precisely estimate the execution time of each responders' actions which may be either impossible or impracticable as it would monopolize various experts in a critical step of the crisis response. Moreover, working at a strategic level, decision-makers don't produce fine-grained plans thus limiting theirs needs regarding explicit time management. One can nonetheless adopt an intermediate position by considering assumption A7 as valid while modelling the execution time of the plan as a preference. In light of this discussion, we believe that assumption A7 should not be relaxed in a crisis management context.

In a nutshell, crisis management planning problems are formalized by relaxing assumptions A1, A5, A6 and A8 of the conceptual model for planning. As produced plans may no longer be sequential, the notion of action is generalized through sets of non mutually exclusive actions denoted *happenings* (see (Fox and Long 2003) for a complete formalization). An happening A contains one or several actions that can be performed concurrently ; when executed in a state s, it leads to an other state $s' = \gamma(s, A)$. Moreover, σ_i is used to denote the real world observation corresponding to the theoretical state s_i.

Crisis Management Planning Problem. Given $\Sigma = (S, A, \gamma)$ a state-transition system, $s_0 \in S$ an initial state and $S_{G'} \subseteq S$ the set of the states verifying the extended goals G', let X denote the set of sequences of happenings $\langle A_1, \cdots, A_n \rangle$ corresponding to the sequences of states $\langle s_0, \cdots, s_n \rangle$ such that $s_1 = \gamma(s_0, A_1), \cdots, s_n = \gamma(s_{n-1}, A_n)$ and $s_n \in S_{G'}$. Let $\gtrsim$ be a partial order over X constructed from the extended preferences of the problem. A plan x is said to be an optimal solution if $\forall x' \in X, x \gtrsim x'$. The crisis management problem consist to:

1. Find a solution plan $x \in X$ given Σ, s_0 and G'. Plan x is not required to be optimal but is expected to be optimized with respect to the partial order $\gtrsim$.
2. Provide a procedure to compute a distance d_i between each state s_i of x and its corresponding observation σ_i. This procedure is used to trigger dynamic planning mechanisms whenever d_i is greater than some threshold θ.

The remainder of this study only focuses on the first part of the crisis management planning p roblem. The second part of the problem can be solved using approaches from the automated planning community (Ghallab et al. 2016) or from the crisis management community (Bénaben, Montarnal, et al. 2017; Barthe-Delanoë et al. 2014).

INFORMATION SYSTEM FOR PLANNING IN CRISIS MANAGEMENT CONTEXT

This section describes core features that an information system producing plans in order to support the crisis managers should possess. Such a system is intrinsically a decision support system and should not be exclusively reduced to an automated planning tool. If it were the case, the system would have little to no added value for the decision-makers. Indeed, automated planning tools process inputs expressed in a formalism unknown to the operational experts of crisis management which is named PDDL (McDermott et al. 1998) and provide no extra information regarding their outputs. These observations highlight two operational requirements that the aforementioned decision support system should fulfil. First, in order for the system to be used effortlessly, decision-makers should be able to describe the problem they are trying to solve using terms from the operational language of crisis management. Indeed, it is inconceivable to ask them to learn a scientific formalism for this p urpose. Moreover, as the system aims to assist the crisis managers in their decision process, it should provide them some explanations regarding the plans it suggests. Therefore, it allows decision-makers to fully understand the recommendations of the system and decide whether they want to follow them or not.

Figure 2 describes a conceptual information system for planning in crisis management context addressing the aforementioned operational requirements. This system is used by executing three successive steps. The *modelling step* allows decision-makers to formalize the problem to solve using their operational language. Models they produce are then automatically transformed into a PDDL problem. Should they want to consider various strategies to handle the situation, the system allows decision-makers to provide several models of their preferences. During the *planning step*, a planner is used to construct a solution plan for each preference model specified by the decision-makers. In order to support the decision, each plan is evaluated against all available preference models. Finally, the *decision-making step* helps the members of the crisis cell to compare the suggested plans so they can choose the one they want to deploy.

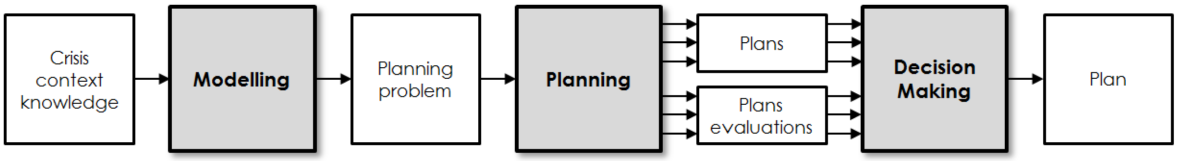

Figure 2. Aid decision system supporting decision-makers during the construction of crisis management plans

During the modelling step, decision-makers create four models (situation, organizations, goals and preferences) based on information they possess regarding the critical situation. One should note that the modelling choices made constitute a decision-making act since the solution plans are directly produced from these models. The *situation model* contains all the relevant elements of the world that should be considered thus providing a description of the initial situation of the crisis. In addition, each organization involved in the crisis response fulfils an *organization model* specifying the relevant actions it can execute as well as its available resources. The objectives that the crisis managers want to achieve are described in the *goals model* and their preferences are captured through *preferences models*. The higher the score of a plan against a preference model, the more satisfactory it is from the point of view of decision-makers. Metamodelling is the keystone of such a knowledge representation. A metamodel is a set of concepts and rules referring to those concepts used to construct models. It imposes a structure in the representation of the knowledge of the considered domain. Thus, it helps users to efficiently create models while ensuring that their models will be coherent enough to be handled by automated processing tools. Several metamodels for crisis management have been proposed, see for instance (Bénaben, Lauras, et al. 2016). Once operational models have been constructed, a *model transformation* (Truptil et al. 2010) is used in order to produce the corresponding planning problem. When a model transformation is performed, concepts from a *source metamodel* are automatically converted into concepts of a *target metamodel* using some predefined mapping rules. Such a transformation is possible since a metamodel for planning (which can be thought of as an abstraction of the PDDL language) intrinsically encompasses many concepts used in a metamodel for crisis management as explained in (Bidoux 2016).

Based on the outputs of the modelling step, the planning step produces several candidate plans as well as their respective evaluations. Decision-making step allows crisis cell's members to visualize the suggested plans. The system also provides information on the proposed plans with respect to each of the decision-makers' preferences. These information should help decision-makers to understand the plans' scores regarding the preference models considered thus allowing them to efficiently compare solution plans and take informed decisions. Moreover, crisis managers have the possibility to perform modifications on the suggested plans if necessary. Finally, if propositions made by the system are unsatisfactory, decision-makers may choose to ignore them or to modify their input models in order to ask for new ones.

Practitioners often perform the three aforementioned steps manually by writing relevant information on a flip chart. Therefore, using the proposed system should be no longer than a manual solving provided that the system's user interface is properly designed. The next section describes a proof of concept implementation of such a system.

PROOF OF CONCEPT IMPLEMENTATION

The proposed system aims to support crisis decision-makers operating at a strategic level. Designing scenarios illustrating their work that are both operationally accurate and easy to understand is a complex task. Indeed, such use cases may include hundreds of operational elements to consider, dozens of organisations to manage as well as numerous objectives to achieve and therefore can not be described concisely. In a attempt to produce the most pedagogical use case possible, we choose to illustrate the considered system at an operational level but we stress out that mechanisms detailed hereafter also remain valid at a strategic level. Hopefully, this scenario inspired from the EU-funded FP7 project SECTOR (Cinque et al. 2015) is nonetheless informative enough to highlight the main features of the proposed system.

The aforementioned scenario describes a massive flood event in Northern Europe. More precisely, it takes place in the vicinity of Roermond, a town located in the region of Limburg in the Netherlands. These events occur during a winter throughout which heavy rainfalls were recorded for several months. As a result, rivers' levels reached their highest points. Meanwhile, weather forecasts indicate that heavy precipitations are still expected. Unfortunately, Roermond area is particularly exposed in case of flooding as it is crossed by numerous lakes and rivers. The goal of this use case is to handle in the most efficient way the crisis that is going to be caused by the incoming flooding. Management of this critical situation mobilizes responders for several days. During this period, decision-makers are expected to produce several plans and use a dynamic planning approach to this end. This section only illustrates the first use of the system namely the construction of the initial rescue plan.

Decision-makers describe the crisis they have to solve by creating the *situation*, *organizations*, *goals* and *preferences models*. The system provides modelling tools that allow them to quickly represent the situation while forbidding the use of elements or relationships that are not conform with the considered metamodel. For conciseness, the creation of the situation model will be the only one illustrated hereafter (cf. figure 3). Using, for instance, the metamodel presented in (Bidoux 2016), decision-makers are permitted to use the concepts of *environment component* (blue rectangle with rounded edges), *eventuality* (purple trapezium) and *state* (green ellipse) to depict the initial situation. These concepts can be linked to one another according to the metamodel's rules. Indeed, an environment component can *generate* (gray arrow) an eventuality or *impact* (violet arrow) another environment component. In addition, environmental components are *characterized* (green arrow) by their states.

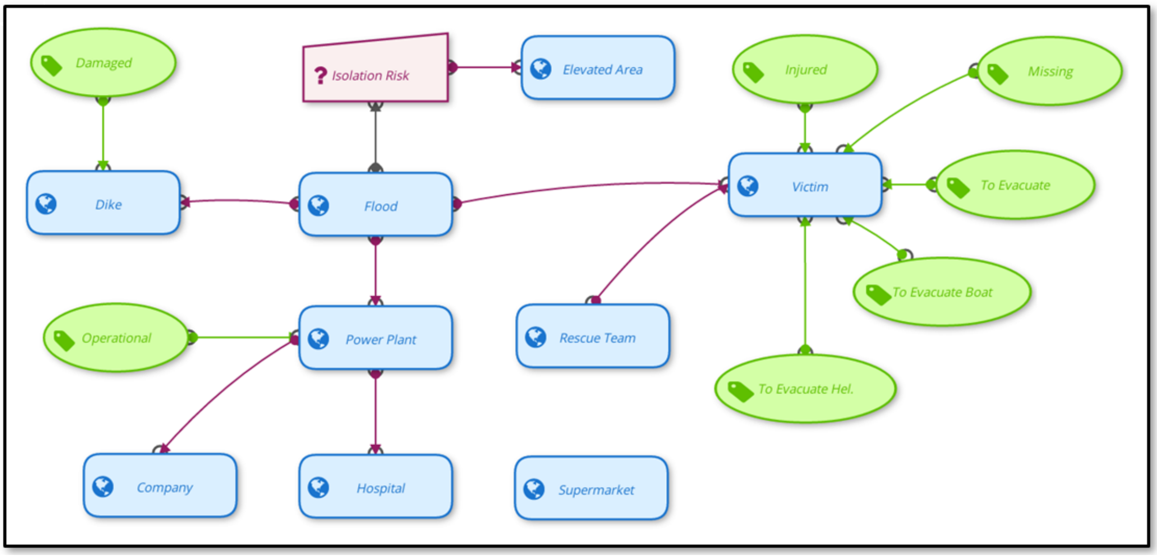

Figure 3. Situation model corresponding to the use case

Although the flooding was anticipated, it occurred sooner and faster than expected due to a climatic event whose magnitude was underestimated. As a consequence, some preventive measures have not yet been deployed at the beginning of the crisis. Unsurprisingly, the main environment component of the model is the *flood* to be handled. It damaged a *dike* and is impacting a *power plant* that currently supplies both the *hospital* of Roermond as well as production facilities of a large *company* of the region. Moreover, it also generates an *isolation risk* for the inhabitants of an *elevated area* which although non-floodable might become completely inaccessible if the water level keeps growing. In addition, the flood has engendered several *victims*, which may be *injured*, *missing* or have to be *evacuated* (by boat or helicopter in the most difficult cases). One should note that the presented situation model has been simplified for illustrative purposes as, given the modelling choices performed, one environment component should have been created for each victim.

Even if the organizations and goals models are not illustrated for conciseness, their content is briefly described hereafter. Most of involved partners are Dutch first responders (*Dutch fire department*, *Dutch police* and *Dutch Red Cross*) or local actors (*electricity provider*, *Roermond hospital*, a *local supermarket*. . .). In addition, international assistance (*German police*, *German Red Cross*, *Belgian Red Cross*) may be mobilized to strengthen Dutch forces if necessary. Each organization is asked to provide a list of the actions it can execute as well as a list of its shareable resources. In this use case, the main goal of decision-makers is to rescue the various victims of the flood. Moreover, they want to place the hospital of the town on alert and set up a temporary reception center for victims. Furthermore, the power plant must be closed as it is threatened by the flooding. Beforehand, hospital should be supplied with generator sets to ensure that it remains operational. Law enforcement operations (dissemination of safety instructions, traffic regulation. . .) are also considered in order to efficiently manage the road network of the region (priority to rescue operations and food provisioning for instance).

Preference models of the crisis managers are made with the Myriad software (Labreuche and Lehuédé 2005). The latter uses a formalism from multicriteria decision analysis in order to represent more accurately the intrinsic complexity of crisis managers' preferences. Furthermore, it allows decision-makers to construct a mathematical model of their preferences using only operational information. As a result, crisis managers are not required to have any mathematical background in order to use the Myriad software. Once the preference models are built, they can be imported into the system through a dedicated interface. In this example, decision-makers realize three preferences models that correspond to three resolution strategies they envision to implement. The first one assesses the crisis response using three criteria: (i) *efficiency* of rescue operations (modeled by the number of rescue teams deployed) ; (ii) the *comfort* of the inhabitants living in the area exposed to an isolation risk (which depends on whether food and electricity is supplied to them or not) and (iii) the *cost* of the response (excluding costs related to victim rescue). It also prohibits to request the international assistance proposed by neighboring countries so that decision-makers can assess the quality of the plan they would be able to deploy with Dutch rescue teams only. The second preference model utilizes the same criteria as the first one without forbidding the use of the international assistance. Decision-makers may therefore estimate the added value provided by the intervention of German and Belgium rescue teams. The last preference model includes an additional criterion regarding production facilities of the local company. Indeed, a brutal shutdown of the power plant could damage these production facilities thus leading to economic losses for the region in the medium term. As a result, the third model also considers a trajectory preference, denoted *company*, that reflects the will to supply the production facilities of the company using generating sets before shutting down the power plant. Production facilities could then nominally finish their production cycle before being stopped, thus avoiding damage to its machineries and infrastructures. In addition, these preference models can take into account the binary interactions that may exist between the aforementioned criteria. Two criteria may be considered as complementary (decision-makers are satisfied only if both criteria are satisfactory), substitutable (decision-makers are satisfied if at least one of the criteria is satisfactory) or independent (decision-makers satisfaction regarding one criterion is not influenced by the other one). In the first two models, *efficiency* and *comfort* are modelled as slightly complementary. In the third model, *cost* and *company* are modelled as substitutable criteria.

Once the four models describing the crisis have been realized, they can be transformed into crisis management planning problems formalized in the PDDL language thus ending the modelling step. More precisely, these problems are described using a PDDL extension which improves the language expressiveness regarding the representation of preferences. Using this extension, one can benefit from the advantages related to the aforementioned multicriteria decision analysis approach as explained in (Bidoux 2016). Throughout the planning step, a planner is used in order to solve crisis management planning problems that have been derived from crisis managers' models. Planning with preferences requires to find a good trade-off between objectives to achieve and preferences to optimize. Indeed, if solving is only focused on objectives, it is easy to find solutions but these are likely to be mediocre ones with respect to the preference model considered. On the other hand, if solving is only focused on preferences, it may even be hard to find a solution due to combinatorics of the problem. The preference-based planner ChoPlan have been used to solve the crisis management planning problems. Details regarding the heuristics it employs are outside the scope of this paper but an interested reader may refer to (Bidoux 2016). In this example, the ChoPlan planner is used to produce three solution plans as three preference models are considered by the decision-makers. Each solution plan is optimized with respect to one preference model but nonetheless evaluated against all preference models thus leading to nine evaluations in this use case. An interface permits to visualize (and modify if necessary) the proposed solutions as illustrated with plan 2 on figures 4 and 5.

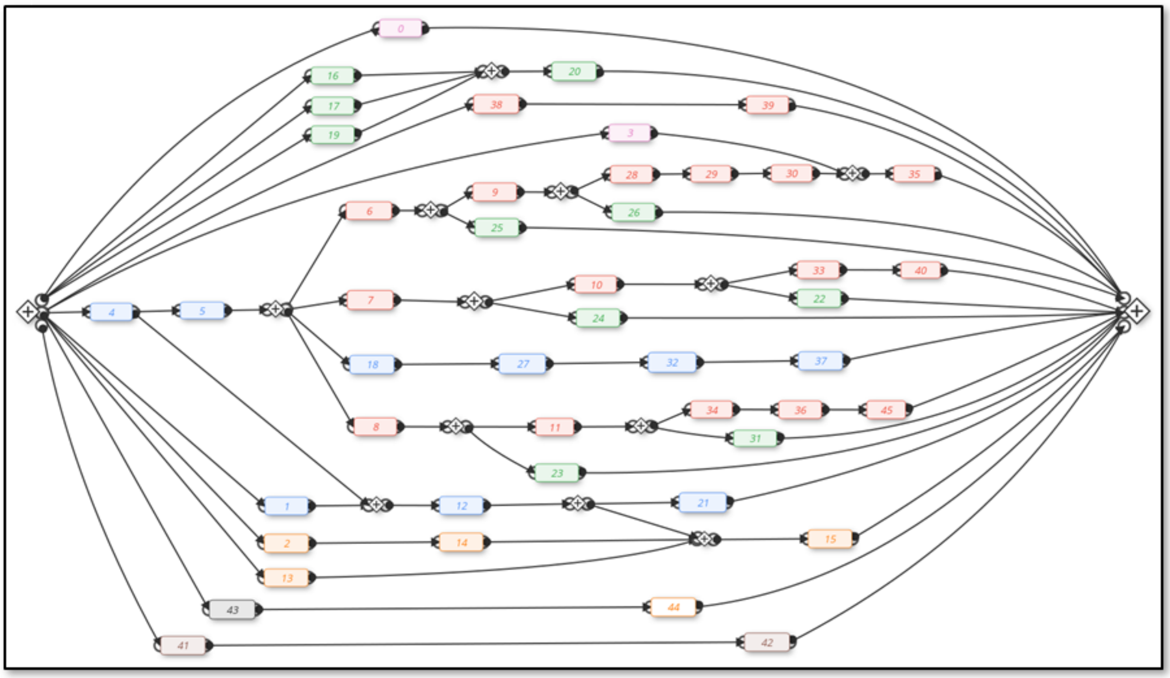

Figure 4. Plan 2 displayed in a non sequential way

```
Plan 2

0. Request_International_Assistance
1. Broadcast_Security_Guidelines du-police-team2
2. Install_Beds_Temporary_Reception_Center
3. Provide_Helicopter
4. Elaborate_New_Road_Circulation_Plan du-police-team1
5. Deploy_Prioritary_Circulation_Axis hospital1 du-police-team1
6. Evacuate_Victim victim17 du-firefighter-team3
7. Evacuate_Victim victim11 du-firefighter-team4
8. Evacuate_Victim victim09 du-firefighter-team5
9. Evacuate_Victim victim20 du-firefighter-team3
10. Evacuate_Victim victim05 du-firefighter-team4
11. Evacuate_Victim victim04 du-firefighter-team5
12. Deploy_Prioritary_Circulation_Axis receptionCenter1 du-police-team2
13. Supply_Food_Temporary_Reception_Center
14. Deploy_Dispensary_Reception_Center receptionCenter1 du-redCross-team1
15. Open_Temporary_Reception_Center
16. Transfer_Hospital_Patients
17. Mobilize_Additional_Hospital_Personal
18. Reinforce_Dike du-police-team1
19. Execute_Alert_State_Supply
20. Put_Hospital_In_Alert_State
21. Regulate_Road_Traffic du-police-team2
22. Heal_Injured_Victim victim05
23. Heal_Injured_Victim victim09
24. Heal_Injured_Victim victim11
25. Heal_Injured_Victim victim17
26. Heal_Injured_Victim victim20
27. Search_Missing_Victim victim14 du-police-team1
28. Evacuate_Victim_By_Boat victim07 du-firefighter-team3
29. Evacuate_Victim_By_Boat victim12 du-firefighter-team3
30. Evacuate_Victim_By_Boat victim13 du-firefighter-team3
31. Heal_Injured_Victim victim04
32. Search_Missing_Victim victim15 du-police-team1
33. Evacuate_Victim victim19 du-firefighter-team4
34. Evacuate_victim victim18 du-firefighter-team5
35. Evacuate_Victim_By_Helicopter victime03 du-firefighter-team4
36. Evacuate_Victim victim10 du-firefighter-team5
37. Search_Missing_Victim victim16 du-police-team1
38. Evacuate_Victim victim08 du-firefighter-team2
39. Evacuate_victim victim06 du-firefighter-team2
40. Evacuate_victim victim02 du-firefighter-team4
41. Provide_Electricity_To_Hospital_Using_Generator_Sets
42. Stop_Power_Plant
43. Provide_Food_Supply
44. Distribute_Food_Elevated_Area ge-redCross-team1
45. Evacuate_Victim victim01 du-firefighter-team5
```

Figure 5. Plan 2 displayed in a sequential way

As part of the decision-making step, the system displays the scores of each solution plan with respect to each preference model in order to help crisis managers choosing the plan they want to deploy (see figure 6). In addition, decision-makers may complement this results overview by considering additional comparison criteria if necessary. Such criteria can be added once the planning step has been performed. They may be used to import evaluation scores regarding the proposed plans from external tools such as simulation ones for instance. Several methods have been proposed to assess action plans in emergency context, see for example (Núñez et al. 2016).

Summary	Model 1	Model 2	Model 3	Min	Max	Average
Plan 1	**58 %**	58 %	58 %	58 %	58 %	58 %
Plan 2	0 %	**81 %**	81 %	0 %	81 %	54 %
Plan 3	0 %	78 %	**86 %**	0 %	86 %	55 %

Figure 6. Scores of the solution plans in the use case

The only difference between preference models 1 and 2 concerns the constraint on the use of international assistance. The first plan (which is obtained by optimizing the first preference model) is the only solution respecting this constraint thus explaining that plans 2 and 3 have a null score with respect to preference model 1. Scores of plans 1 and 2 regarding preference model 2 can be interpreted thanks to diagrams presented in figure 7 . Indeed, decision-makers have considered the response efficiency as the main criterion of this model since it is responsible for 50% of the score. In addition comfort and cost criteria both impact 20% of the score. The remaining 10% are due to a complementarity between efficiency and comfort criteria. Thus, this part of the score favors plans that are conjointly satisfactory on these two criteria. Such a case occurs for example with the second solution plan whose efficiency and comfort scores are both relatively similar and high (see bar charts in figure 7). Nevertheless, one can observe that for solution plan 1, the score of the comfort criterion is considerably weaker than the score of the efficiency criterion. The second plan differs from the first one because it resorts on the international assistance offered by Germany and Belgium. As a result, there are more rescue teams mobilized in plan 2 which impacts positively its efficiency criterion. Indeed, Red Cross teams are strengthened thus enabling this organization to carry out an additional mission in the second plan (food provisioning to the inhabitants of the area which is going to be isolated). The second plan therefore obtains a better score with respect to comfort criterion. However, its score regarding cost criterion is lower than the one of the first plan due to the costs engendered by this food distribution.

Furthermore, plans 2 and 3 can be compared with respect to preference model 3 using diagrams from figure 8. Preference model 3 presents some similarities with preference models 1 and 2 since efficiency criterion weights for 50% of the score, cost criterion represents 20% of the score and the complementarity between efficiency and comfort criteria also account for 10% of the score. Nevertheless, the remaining 20% of the score are defined by an interaction between cost and company criteria. Indeed, in this model, these two criteria are completely substitutable one to another. Thus, a good score on the company criterion can offset a bad cost of the solution and vice versa. Contrary to the second plan, the third solution (which is obtained by optimizing the third preference model) respects the preference regarding the power supply of the company's production facilities. As a result, the score of the third plan according to the company criterion is maximal. On the other hand, its score on the cost criterion is worse than the one of the second plan 2 due to the expenses engendered to supply electricity to the company. Since these two criteria are substitutable for one another, plan 3 surpasses plan 2 according to the third preference model.

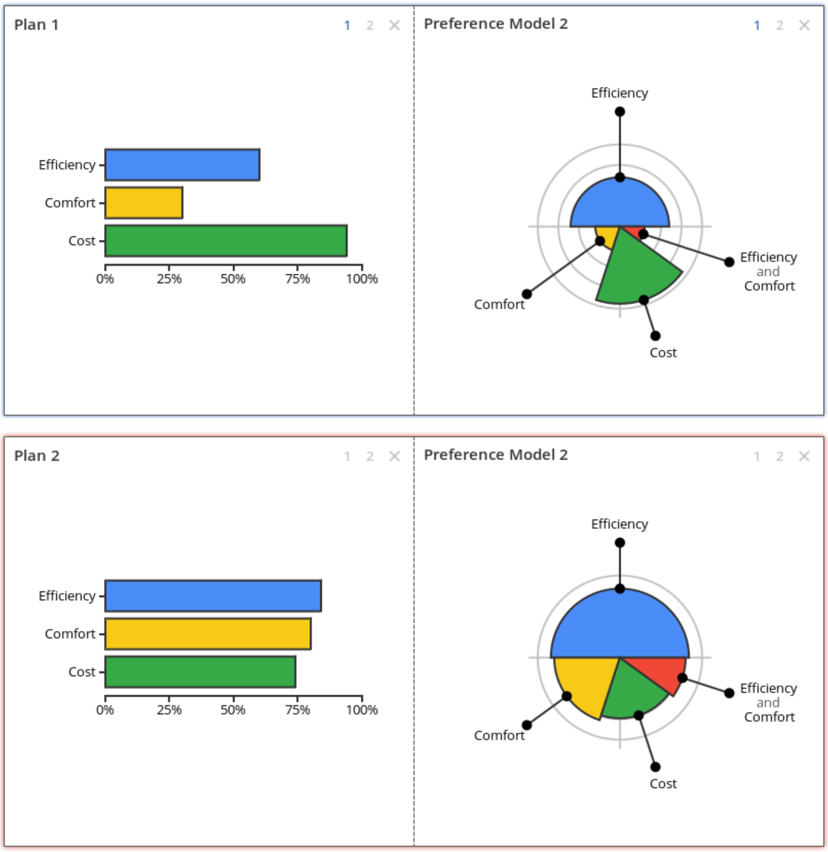

Figure 7. Comparaison of plans 1 and 2 with respect to preference model 2

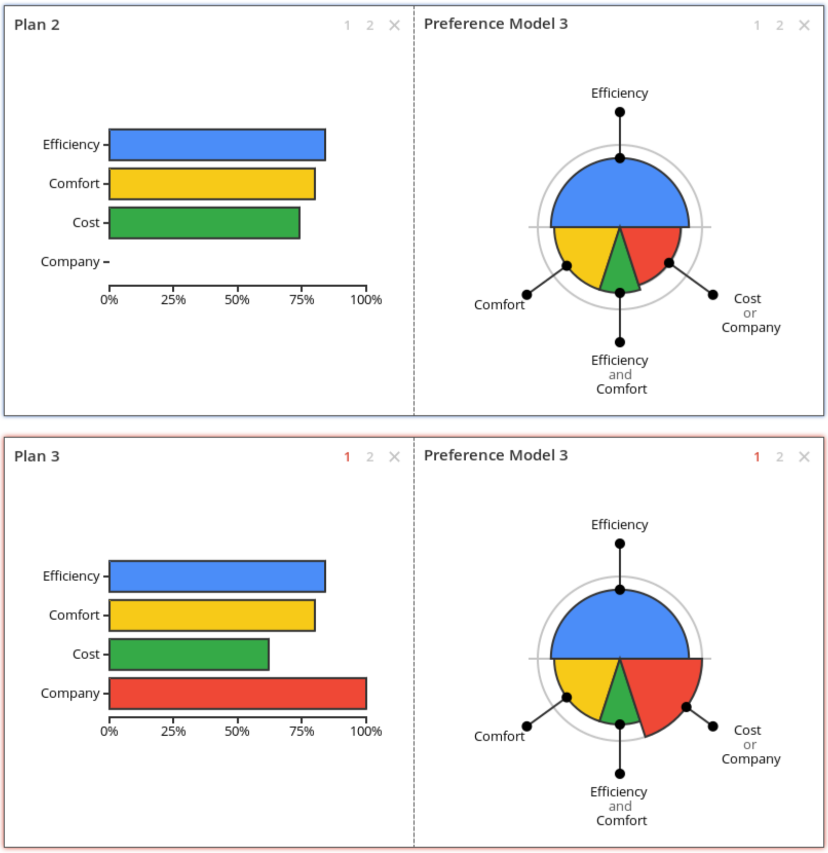

Figure 8. Comparaison of plans 2 and 3 with respect to preference model 3

In this use case, crisis managers finally choose to deploy the third plan. Indeed, it may seem unwise in this example not to resort on the aid of international partners in light of their impact on the quality of the response. Moreover, additional costs associated with the third plan seems acceptable to decision-makers given the advantages of the latter compared to the second plan.

CONCLUSION

In this paper, we have discussed the use of automated planning for crisis management. On the theoretical side, we have formalized the crisis management planning problem in light of the various assumptions of the conceptual model for automated planning. In order to address this problem, one have to (i) find a plan solving the considered problem and (ii) detect divergences between the expected situation and the real world during the plan's deployment. On the practical side, we have described some operational requirements that an operational system addressing the first part of this problem should possess. In addition, a conceptual information system satisfying these operational requirements have been proposed. A proof of concept implementation of this system has also been described through an operational use case involving a massive flood event in Northern Europe.

An interesting perspective regarding the theoretical formalization of the crisis management planning problem would be to study the case obtained when assumption A7 of the conceptual model for automated planning is also relaxed. On the practical side, a notable perspective would be to improve the modelling step of the aforementioned system. Indeed, assisting decision-makers by suggesting them elements to consider (or even by generating some parts of the models automatically) and by highlighting potential problems in their models would be a great addition. Such a feature could be implemented using inference mechanisms on an ontology populated with experts' feedbacks from past crises. To finish, the main perspective for this work would be to extend the proposed system so that it addresses the second part of the crisis management planning problem too. As a result, one may obtain a fully functional information system supporting decision-makers' planning activities in crisis management contexts.

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Towards using Volunteered Geographic Information to monitor post-disaster recovery in tourist destinations

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ABSTRACT

The aftereffects of disaster events are significant in tourist destinations where they do not only lead to destruction and casualties, but also long-lasting economic harms. The public perception causes tourists to refrain from visiting these areas and recovery of the tourist industry, a major economic sector, to become challenging. To improve this situation, current information about the tourist and infrastructure recovery is crucial for a "rebranding"- information that is however time and cost-intensive in acquisition using traditional information sources. An alternative data source that has shown great potential for information gathering in other disaster management phases, which was less considered for disaster recovery purposes, is Volunteered Geographic Information (VGI). Therefore, this paper introduces a VGI-based methodology to address this task. Initial analyses conducted with Flickr data indicate a potential of VGI for recovery monitoring, whereas the analysis of OpenStreetMap data shows, that this form of VGI requires further quality assurance.

Keywords

OpenStreetMap, Flickr, Disaster, Recovery, Tourism

INTRODUCTION AND BACKGROUND

Disasters pose serious threats to affected communities and environments all around the world. Such events not only cause immediate effects in the disaster-affected areas, but also lead to long-term burdens over post-event recoveries. Post-disaster recovery is especially challenging for tourist destinations, as the image and reputation of the regions is harmed. Tourists may be hesitant to visit an affected tourist destination even though the region has physically recovered as a result of the tourists' perception that the latter does not fit the image of a holiday place. Apart from this, uncertainties regarding safety and the level of reconstruction lead tourists to avoid visiting the affected tourist destination (Walters and Mair, 2012). For this reason, the image restoration of a disaster affected destination is as important as (or even more important than) fixing physical damages, which has been termed as "rebranding" in Amujo and Otubanjo (2012).

For restoring the image, information regarding the current status of recovery in terms of security, the local services, and tourist attractions is needed (Walters and Mair, 2012). While there are studies and approaches to gather recovery information using satellite imagery, on the ground surveys, and interviews, these methods demand expert knowledge, specific training, and software, and are therefore costly and time-consuming (Platt et al., 2016). An alternative data source that has shown to provide great potential for disaster management purposes is Volunteered Geographic Information (VGI)- data that is voluntarily created and maintained by international volunteers and the disaster affected people themselves (Horita et al., 2013; Liu and Palen, 2010; Meier, 2015; Poiani et al., 2015). Due to the real-time character, outreach, and cost-effectiveness of VGI, the data is increasingly utilized to support disaster management purposes. OpenStreetMap (OSM) is hereby used to gather current map data of the disaster location, including disaster related information, e.g. temporary shelters or infrastructure damage (Anhorn et al., 2016; Westrope et al., 2014). In turn, social media data is frequently used for event detection and to obtain situational awareness (Vieweg et al., 2014; Vieweg et al., 2010; Imran et al., 2014). While these potentials of VGI could be put in use in all disaster management phases, to date VGI has been almost exclusively utilized for the response and preparedness phase of disasters. In turn, its use for disaster recovery has been less explored (Horita et al., 2013; Haworth and Bruce, 2015). Accordingly, there are also no experiences in using VGI for the monitoring of recovery in specific locations, e.g. tourist destinations.

In order to close this research gap, the aim of this paper is to analyze the suitability of VGI in monitoring the disaster recovery of disaster affected tourist destinations by monitoring the level of recovery and tourist activity. The remainder of this paper is as follows. The next section provides an overview of the previous research on the use of VGI for disaster management purposes as well as previous disaster recovery studies. The approach and method section introduces our workflow and the methods that have been implemented to assess the research question. After presenting our case study and area of interest, the initial results of the analyses conducted based on the OSM and Flickr data in the area of interest are provided. The discussion, conclusion and outlook provide concluding remarks and ideas for future studies that can build on the insights gained.

RELATED WORK

Over the last couple of years, the use of VGI data for disaster management has grown in popularity. In numerous disasters, e.g. the Haiti earthquake in 2010 (Zook et al., 2010), Typhoon Haiyan in 2013 (Westrope et al., 2014; Vieweg et al., 2014), and the Nepal earthquakes in 2015 (Poiani et al., 2015), this form of data was used to obtain situational awareness, for damage assessment, and coordination purposes.

One form of VGI data that was hereby increasingly utilized is OSM data[1]. The openly available map data is collected in disaster mapping activations which are launched by the Humanitarian OpenStreetMap team (HOT)[2]. HOT is hereby, on the one hand, in contact with the humanitarian aid organizations and, on the other hand, coordinating the OSM mappers to meet the humanitarian aid organizations´ and emergency responders´ needs. The data that is collected by international volunteers of the OSM community enables the localization of disaster related information and can be furthermore used to estimate the level of infrastructure damage in the disaster affected area in the direct aftermath of disasters (Meier, 2015; Westrope et al., 2014). Another OSM related project, Missing Maps[3], was launched in 2014 as a collaboration of humanitarian organizations and HOT with the objective to also make use of OSM data to enable better disaster preparedness and support of humanitarian aid efforts. While the project and the related research again showed the potential of OSM in supporting humanitarian action and disaster preparedness (Porto de Albuquerque et al., 2016; Herfort et al., 2016), to the best of our knowledge the use of OSM data for the recovery phase has been neglected in previous OSM research.

Likewise to the map data creation facilitated by HOT and the OSM community, the analyses of social media data are to a great part conducted by digital volunteers, too. The Standby Volunteer Task Force[4] (SBTF) is one of the main volunteer networks which are activated for disaster response support. By classifying, analyzing, and geo-referencing social media messages provided by the affected population in near-real time, the volunteers can help to obtain situational awareness (Meier, 2015; Vieweg et al., 2010). The use of social media was therefore also increasingly covered in research.

Several studies focused on the different kinds of information social media data could provide for disaster management, while others in turn assessed ways to support the work of the volunteers and facilitate the data

[1] http://www.openstreetmap.org 3.1.2017.
[2] https://www.hotosm.org/ 3.1.2017.
[3] http://www.missingmaps.org/ 3.1.2017.
[4] http://www.standbytaskforce.org/ 3.1.2017.

classification. Studies by Sakaki, Okazaki and Matsuo (2010) and Crooks et al. (2013) showed that analyses of social media data can help to assess the location of a disaster and the affected areas. Further studies by Olteanu, Vieweg and Castillo (2015) and Vieweg et al. (2010) moreover presented possibilities for improving the utilization of social media data for disaster management purposes by assessing the different topics that are covered in social media data in different kinds of disaster events. This approach enabled the evaluation of the sort of information that can be expected from social media in a specific type of disaster. In research conducted by the Qatar Research Institute in collaboration with the SBTF, Imran et al. (2014) introduced a machine learning approach that supports the work of the digital volunteers. Applications like the Artificial Intelligence for Disaster Response (AIDR) facilitate the classification of tweets using manual tweet classifications by volunteers as training data and a machine-learning algorithm for the further classification.

While the results of the presented studies indicate that the assessed social media data also contains recovery related information, the use of social media for information gathering in the recovery phase is still neglected in academia (Olteanu, Viweg and Castillo, 2015). To date the level of recovery and thus “returning to normal” was above all assessed using remote sensing techniques, on the ground surveys, statistics, authoritative and / or commercial data (Brown et al., 2012; Brown et al., 2008; Bolin and Stanford, 1998; Hirayama 2000; Chang and Falit-Baiamonte, 2002).

Examples of such methods have e.g. been introduced in 2008 by Brown et al.. The authors presented a method for identifying indicators of post-disaster recovery using remote sensing and field survey techniques as well as online statistics (Brown et al., 2008). Remote sensing and ground survey techniques were moreover utilized in a study concerning the initial recovery after the Wenchuan Earthquake in 2008 (Brown et al., 2012). The use of surveys has in general been popular for monitoring housing and household recovery (Bolin and Stanford 1998; Hirayama 2000) as well as business recovery (Chang and Falit-Baiamonte, 2002). Platt et al. (2016) again recommend combining different approaches, in their research approach, satellite imagery analyses, ground and household surveys, social audit, commercial and official data, statistics, and VGI. While the authors acknowledge the potential of VGI for disaster management, they doubt the usefulness of VGI for disaster recovery purposes due to an assumed lack of interest by the volunteers in recovery support. An assumption that was however not further investigated. While the introduced traditional methods proved to enable the needed information gathering for disaster recovery monitoring, they require a high level of training as well as specific technology and are time- and cost-intensive (Platt et al., 2016). Moreover, while tourist numbers for monitoring tourist activity are collected and accessible in detailed statistics for most places in our world, there are also countries in which this kind of data is not available or not kept up to date, e.g. in countries on the African continent (Christie et al., 2014; African Development Bank, 2017). In general there are differences in the scale these statistics are available in, which are varying between country and regional level. With OSM and social media having shown potential in the other disaster phases (Liu et al., 2008; Horita et al., 2013) and the use of VGI for supporting these efforts being less explored, the objective of this paper is to assess the potential of this alternative or complementary data source for recovery and tourist activity monitoring, using tourist destinations as an initial use case. In comparison to other social media platforms, e.g. Twitter and Facebook, Flickr offers a higher and easier accessibility as the Flickr API enables to acquire all possible historical Flickr data[5]. In turn, the Twitter API limits the data acquisition to a small one percent sample of the full data (Peters and Porto de Albuquerque, 2015). Facebook is even more restricted on obtaining its users’ data contributions (Solberg 2010). To ensure having a comprehensive data set to work on and which can be assessed for the crucial time of the Bohol earthquake and Typhoon Haiyan, we decided to use Flickr data in this initial study.

APPROACH AND METHOD

Disaster recovery in tourist destinations comprises infrastructure reconstruction as well as the local tourist economy getting back to normal. The focus of the analyses is therefore laid on information gathering about the level of reconstruction and the tourist activity.

Monitoring of reconstruction using OSM data

In a first step, the level of reconstruction is assessed using the OSM data that is added by the OSM community in disaster response mapping activations organized by HOT.

[5] https://www.flickr.com/services/api/ 19.3.2017.

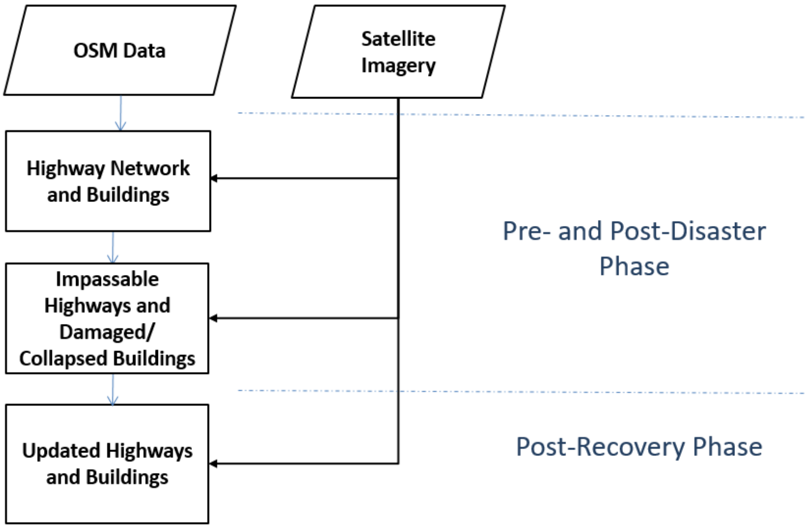

Figure 1. OSM Temporary Disaster Related Tag Workflow

In these activations, HOT organizes and coordinates the mapping activities by providing a selection of regions and features on which mappers should put their focus on. These are communicated by humanitarian organizations and first responders on the ground. In general, mappers are asked to add temporary damage related "tags" to highways and buildings using post-disaster imagery to enable damage assessment and disaster specific routing (Neis et al., 2010; Westrope et al., 2014). Tags are the attributes describing OSM features using a "key=value" structure (Ramm and Topf, 2010). In the case of a disaster mapping activation, damaged highways should be tagged with "status=impassable", obstacles on the road as "barrier=debris". Damaged buildings should be tagged as "building=damaged", totally collapsed buildings with "building=collapsed", and an area of collapsed houses as "landuse=brownfield". All of these tags are temporary additions to already existing OSM features that are added in the post-disaster phase to help emergency responders identify disaster affected areas and facilitate the disaster response coordination. As the tags are used to mark damage, they should be deleted and updated in the OSM database in the post-recovery phase when the reconstruction is finished. Consequently, the decline of these disaster-related tags can be seen as a proxy for infrastructure recovery in the aftermath of a disaster. To test this hypothesis, temporal modifications in the number of disaster-related tags are assessed. These changes can be monitored using the OSM history data in which we can access the state of the OSM database for different points in time. Using the date extension in overpass turbo[6], an OSM service which allows extracting OSM data based on defined tags via the overpass-API, queries can be run considering the specific disaster-related temporal tags and different points in time. The area of interest can hereby be utilized as a bounding box to limit the queried data and the time of computation which depends on the number of queried features. The overpass turbo service enables the export and moreover displaying the number of features that resulted from a query. Queries that are run using the same tag and bounding box for different points in time enable monitoring changes in the assessed tag count.

Monitoring of tourist activity

Economic recovery in tourist destinations is to a great part related to the tourist sector recovery. An increase in tourist numbers in the former disaster affected region can therefore be seen as a sign for economic recovery. To assess the number of tourists within the Flickr users which can facilitate the estimation of the overall tourist activity, a pre-processing of the OSM and Flickr data is conducted followed by the analyses of the VGI data.

[6] http://overpass-turbo.eu/ 3.1.2017.

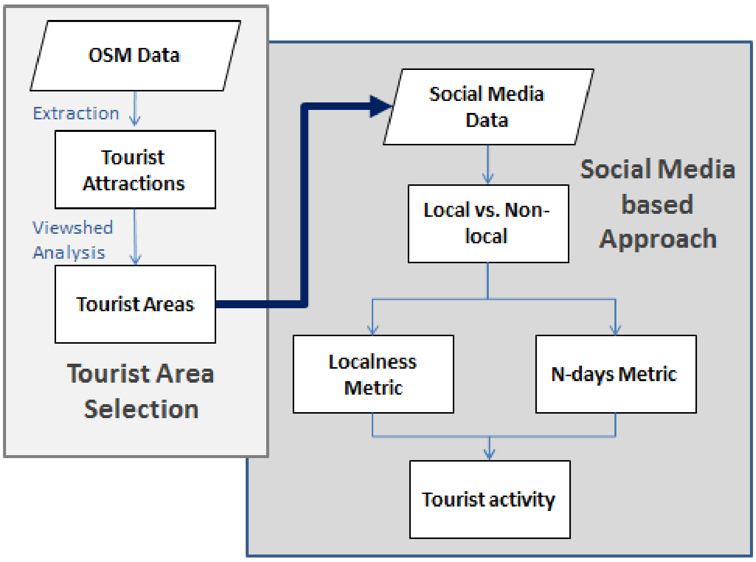

Figure 2. Tourist Activity Monitoring Workflow

In a first step, all relevant tourism related OSM features are selected. These features are assessed by searching for all OSM tagging combinations that are used to describe touristic places in OSM in the OSM Map Features[7]. All features containing a "tourism"-key or "historic"-key and all features that are tagged as "amenity=place of worship" within the area of interest are selected using a bounding box of the area of interest and querying the current state of the OSM database. In the next step, these features are exported using the overpass turbo service to identify all places that could be of relevance for tourists visiting an area. Additionally, to ensure that only relevant social media data is included in the analyses, in the further step, a viewshed analysis is conducted, using the viewshed tool of ArcGIS, on the basis of a digital elevation model (ASTER GDEM 2) and the selected OSM features (Tachikawa et al., 2011). The viewshed analysis provides all places from which at least one tourist sight might be visible considering the given conditions and the terrain. Thus, all tourism data that might have been incorrectly georeferenced can be excluded. Moreover, all social media data with location accuracy less than street-level is removed. In the further analyses, only the social media data within the viewshed is used to ensure a high level of thematic relevancy.

After the pre-processing of the data, initial analyses of the social media data are conducted. Herein the users are classified as tourists or local social media users according to their contributions. Therefore, two different methods are tested and combined. The first approach is the so-called *location field* or *localness metric* (Jurgens et al., 2015). Hereby the home or residential address of the social media users, which can be added in the user profile, is used to assess if a user is a local or non-local. In our case, non-locals are seen as equivalent to tourists and will also be referred to as such in the following. As this method can also imply a certain level of inaccuracy and should be applied in combination with other related methods (Hecht et al., 2011), we additionally apply the *n-days localness metric* to verify the results (Hecht and Stephens, 2014).

In the second method, the time range of the social media posting in a specific area is taken into consideration. Social media contributors that are posting messages for durations less than the defined number of days are herein classified as a non-local, contributors that are providing data for longer than this defined time duration are assumed to be local. Durations of ten days have shown to provide useful results (Hecht and Stephens, 2014; Li, Goodchild and Xu, 2013). For this reason this period of time is also used for our approach. The results of the two methods are compared and the consent data is used for the visualizations and interpretation (Johnson et al., 2016).

CASE STUDY

The Philippines have been selected as the case study for this initial research as the group of islands is one of the major tourist destinations. Tourists are mainly visiting the islands in the dry season from November to April/ May every year[8]. Apart from this, the Philippines are also known to be prone to earthquakes and typhoons[9]. In

[7] http://wiki.openstreetmap.org/wiki/Map_Features 3.1.2017.
[8] http://www.lonelyplanet.com/philippines/weather 3.1.2107.

2013 two of these events affected the islands in a short period of time causing severe harm. After the Bohol earthquake had hit the Philippines on October 15th and caused more than 200 casualties, from November 8th, Typhoon Haiyan caused more than 6000 casualties, nearly 30 000 people to suffer injuries, and around 3.5 million people to be affected in general (Mas et al., 2015). The analyses are focusing on these two events and the time before the disasters as well as the aftermath period.

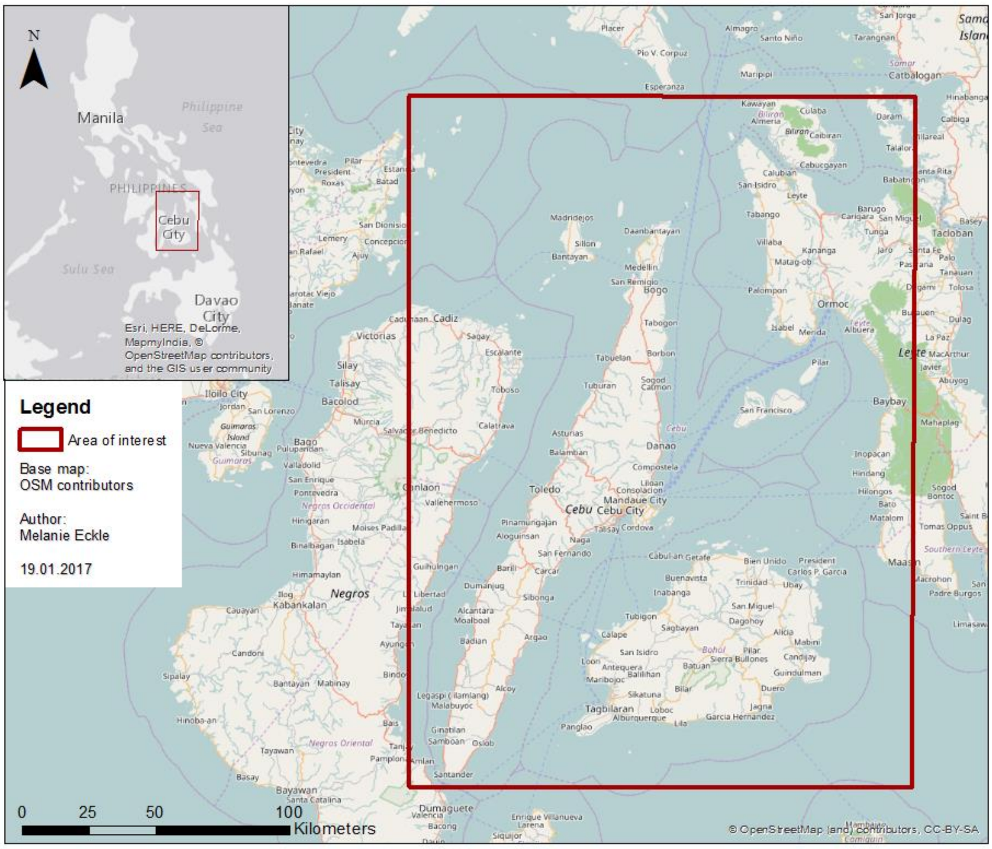

Figure 3. Area of interest

DATA SETS

The VGI data for the case study of the Bohol earthquake and Typhoon Haiyan was extracted from the region around the Central Visayas in the Philippines, one of the main impact areas of the events.

OSM data

All tourism and disaster related OSM data was extracted from the area of interest using overpass turbo. The area of interest was hereby used as a bounding box for our queries using the overpass-API and the current OSM database.

Flickr data

The Flickr photo data collection was done by using a self-developed tool, a FlickrPhotoCrawler, which is developed based on a PHP script and follows the access policy and regulation of the Flickr API. The tool enables the automatic fetching of the Flickr photos including photo ID, owner ID, owner name, title, location (longitude and latitude), accuracy, and the URL for image acquisition and its Exif file recording rich time information of photos, e.g. original datetime, modified datetime and GPS datetime, by flickr.photos.search and flickr.photos.getExif methods, respectively. The FlickrPhotoCrawler fetches Flickr photos by a 0.5 degree x 0.5 degree moving window starting from the upper left corner to the bottom right corner of the study area to completely scan the whole area of interest. Due to the fact that maximum results from each search query of the

[9] http://www.preventionweb.net/countries/phl/data/ 3.1.2017

Flickr API are limited to 4,000, the FlickrPhotoCrawler is recursively doing fetches following the division of quadtree in each grid while the results are over its limitation. Via the FlickrPhotoCrawler, 140,451 non-duplicated photos contributed by 4,744 individual users through July 6th, 2016 are collected in the study area (WGS 84 lat/long, bounding box: 123.220, 9.371, 124.696, 11.604).

RESULTS

Monitoring of reconstruction using OSM data

Our initial results show that there was an increase in ways marked as “status=impassable” as well as “landuse=brownfield” in the aftermath of the two disaster events. More than half of the highways tagged as “status=impassable” were updated after July 2015, the number of tags decreasing from 72 to 30. The number of highways tagged as impassable stayed constant afterwards (status 1/01/2017). A steady decrease of brownfield tags can also be detected after 12 to 18 months. During this time the number of features tagged as “landuse=brownfield” decreased from 247 to 220 and then remained nearly constant after June 2015 (status 1/01/2017: 207 ways, Figure 4). These updates do not seem to be related to changes on the ground, but rather to the attention of individual users. All updates regarding the impassable highways were done by only one local mapper.

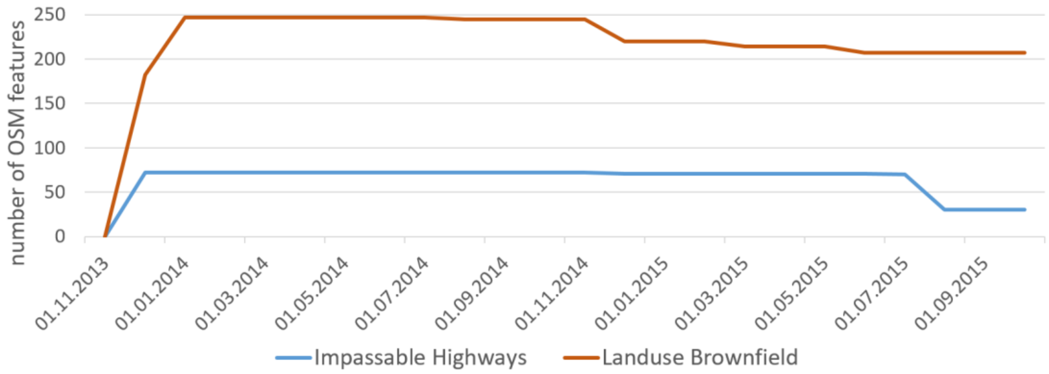

Figure 4. Number of OSM way tagged as “status=impassable” or “landuse=brownfield”

While there was some updating of the impassable highways and brownfield areas, there was less updating of damaged and collapsed buildings tags. Likewise to the other disaster related tags, there is a steady increase in damaged and collapsed building tags at the beginning of the response phase after the disaster. There is however nearly no update of this data afterwards. Around 3% (183 of 5887) of the collapsed and 6% (203 of 3322) of the damaged buildings were updated to date (status 1/01/2017). Only two ways/ seven nodes were marked as “barrier=debris”, their count still being constant till the beginning of the year. Due to the fact that all temporal tags show the same pattern regarding lack of data updating, the latter were not covered in additional figures.

Monitoring of tourist activity

Altogether 544 users provided data as well as a residential or home address in the Flickr data set for the area and time of interest. The *location field approach* in which the users were assessed based on the residential and home address provided in the user profile shows that 140 of these users, can be classified as locals, 404 users in contrast can be classified as tourists. For users within the Philippines, apart from the country, the city of residence was assessed, too. All users, whose city of residence is not within the area of interest, were also classified as tourists. Users that did not provide a location in their user profile were not included. Following the *n-days approach* and setting the duration to 10 days, 252 contributors are classified as local and 1054 as tourists.

When comparing the results of the *location field* and *n-days approach*, there is consent in the data classification for 354 of the overall 544 contributors, which corresponds to around 65%. 328 contributors were classified as tourists considering both approaches. Looking at the number of users that contributed Flickr data in the years before and after the disaster events, changes in the tourist activity become apparent, as shown in Figure 5. The red lines show the time of the Bohol earthquake and Typhoon Haiyan.

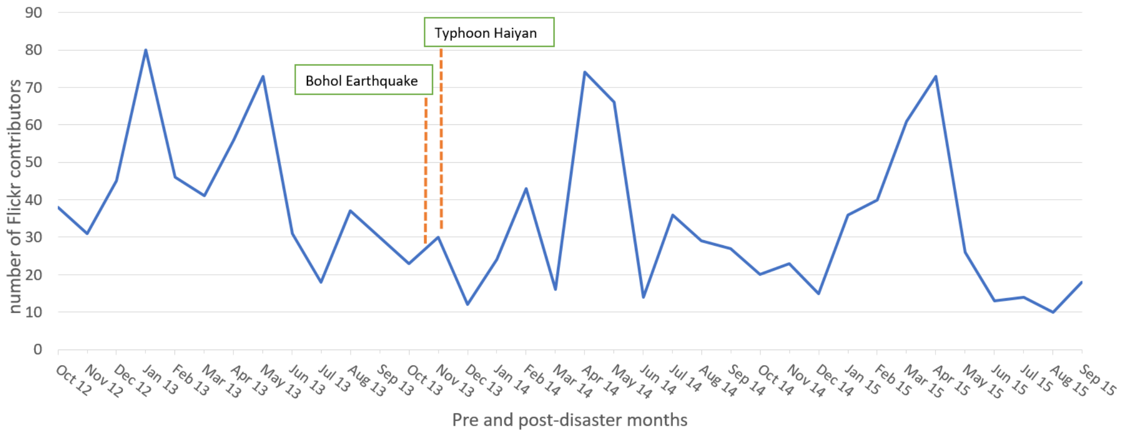

Figure 5. Overview of tourist count in Flickr data before and after the disaster events

The temporal overview shows that there was a decrease in tourist numbers within the Flickr users after the two disaster events. In general, the temporal distribution of Flickr contributors follows the seasonality of the tourist activity. Most tourists visit the area between November and April during the dry season, less tourist come in the rainy season from May to October. For April, the end of the main tourist season, we see a peak in the number of Flickr contributors (with a maximum around 75 contributors per month) for all years. This may lead to the assumption that tourism did not suffer from the two disastrous events. Nevertheless, when looking at the number of Flickr contributors for the months of November and December, differences are visible. In November 2012, our dataset shows a high number (80) of Flickr contributors compared to around 30 in November 2013 and around 25 in 2014. The data suggests that the overall number of Flickr contributors was lower after the disaster events in comparison to the number of contributors before the events, reaching the lowest number of Flickr contributors in December 2013 directly after Typhoon Haiyan had hit the Philippines. The low numbers for the years after the disasters may indicate a drop in the overall tourist activity, which could be an indicator for the unfinished recovery process.

DISCUSSION

OSM data shows potential for being utilized to estimate the level of reconstruction of highways and buildings, Flickr data could, in turn, facilitate the monitoring of tourist activity. While the results of the data assessment conducted with Flickr data indicate a potential of VGI for recovery monitoring, the analyses of data from OpenStreetMap show, that this form of VGI requires further quality assurance. For this reason, there are several further steps that need to be taken into consideration to allow better usability of the data.

Monitoring and updating of temporal OSM data in former disaster regions has already been recognized as an issue and is currently discussed in the OSM community (Anhorn et al., 2016). The results of this study emphasize that especially the disaster related OSM features are not regularly updated or not updated at all. The work of local organizations like Kathmandu Living Labs[10] in the direct aftermath but also during the long term recovery after the Nepal Earthquake 2015 confirms the value and importance local volunteers have regarding data updating and maintenance and, thus, OSM data quality.

Furthermore, Westrope et al. (2014) show that the quality of the damage mapping in OSM is rather poor. In their study only 36% of the damaged buildings were tagged correctly. This is backed by Kerle and Hoffman (2013) who show that collaborative damage mapping poses several challenges regarding the mapping instructions, the resolution of the satellite imagery, and the coordination of volunteers. Platt et al. (2016) furthermore state that a lack of interest in the post response phase causes a decrease in the mapping activity. Taking this into account, the results of this initial study also show that OSM needs to undergo further data quality assurance before being useable for the monitoring of reconstruction or recovery.

The monitoring of the activity of tourists within the Flickr users indicates different patterns before and after the disaster events. While the tourist season in general starts in November and lasts till April/ May, in the year of the disaster the tourist activity seemed to be delayed and dropping again before reaching a similar count as the year before and after the disaster events. Therefore, the results of this study underline the findings of Sun et al. (2013) that Flickr photos can help to get deeper insights into tourist accommodations and can illustrate seasonal tendencies. While this initial study did not include spatial analyses, future work should investigate whether the detected tendencies can be described in more detail by taking spatial correlations into account. The spatiotemporal analyses could also help to detect further patterns as post-disaster recovery may not be uniform in the whole disaster area (Brown et al., 2008).

CONCLUSION AND OUTLOOK

The presented study provides an example for integrating VGI data into disaster recovery monitoring in tourist destinations. However, to enable putting the presented approach into use and getting dependable results, further assessments are needed including quality assurance and taking different aspects into account, e.g. intrinsic data quality parameters. An active local OSM mapping community and regular updates on other, non-disaster related OSM features, may allow predictions about the quality of damaged buildings and impassable highways. This is relevant as a lot of the data updating can only be done by local mappers who collect data locally without being dependent on current satellite imagery.

In the past, activations of the Humanitarian OpenStreetMap team mostly focused on the disaster response phase. In this phase, HOT develops specific mapping tasks and coordinates the efforts of thousands of OSM contributors. Community working programs, local chapters of HOT in different parts of the world, increasing support of local mapping communities, e.g. through Microgrants[11], and the cooperation with humanitarian aid organizations in the Missing Maps projects however also facilitate local mapping, updating and validation of OSM data, and therefore more sustainable data maintenance. Extending this approach can help to improve the current database in different parts of the world without exclusively relying on remote mappers. The latter could moreover be included by making use of already existing OSM tools, e.g. MapRoulette[12], which could be used to remotely detect errors and also identify temporal data that is due to be updated. Other already existing tools that could be adapted for this approach are the OpenFloodRiskMap (Eckle et al., 2016) and OSM Analytics[13]. While the OpenFloodRiskMap enables filtering and identifying critical infrastructures in an area of interest using the OSM database, OSM Analytics enables monitoring differences in building and highway numbers over time by displaying the last edit of OSM features. Extending the feature catalogue of OSM Analytics or integrating OSM history functionality and temporal OSM tags into the OpenFloodRiskMap feature catalogue could help enable more OSM contributors to easier monitor performed and neglected data updates. Yet, to facilitate this remote mapping support, a more frequent update of the satellite imagery covering the disaster prone and less mapped regions of the world is needed. In the direct aftermaths of a disaster, such as Typhoon Haiyan, such imagery is provided due to the International Disaster Charta[14], current imagery is however less accessible for other disaster phases. In the presented area of interest in the Philippines, post-disaster Bing imagery is only available for a small part of the area[15]. While imagery, e.g. for the southern part of Bohol, is available for December 2014, the imagery in the other areas dates back to 2011 and 2012. This limited accessibility of imagery hinders the remote mapping in the recovery phase.

Regarding the Flickr data assessment, the *location field* and *n-days approach* limited our analyses to users that provided information about the home or residential address and were providing data for a similar range of time in the area of interest. Future research could also include other localness approaches that allow coverage of further aspects of the users. Future analyses could also consider the content of the social media data, in our case the Flickr images, which can help to get an idea not only of the tourist activity, but also of the situation on the ground and how it is perceived.

In general, the representativeness of Flickr photos is of great concern for this research as Sun et al. (2013) showed that it is not very well. This poses a serious limitation to the results of this study. Further analysis could be conducted using different forms of social media and a larger study area to enable confirming the potential trends. The limitations also suggest that VGI data from Flickr are not an exclusive source of geographic information to monitor tourist destination recovery. VGI could hereby be rather used as a complementary source of information to validate official information or add details. Thus, further research could also expand the approaches proposed in this paper to combine VGI and other data sources and thereby help to improve existing resources.

In general our approach can help to identify which areas are more and less recovered. Consequently, the results support decision making regarding places that need special attention for reconstruction activities. Moreover, the

[11] https://www.hotosm.org/updates/2016-12-06_funds_for_community_led_projects_the_2017_hot_microgrants_program 19.3.2017.
[12] http://wiki.openstreetmap.org/wiki/MapRoulette 19.3.2017.
[13] http://osm-analytics.org/ 19.3.2017.
[14] https://www.disasterscharter.org 19.3.2017.
[15] http://mvexel.dev.openstreetmap.org/bing/ 15.1.2017.

approach enables the detection of better recovered areas and, thus, supports decision makers in tourist agencies to decide which places to advertise for tourists. Additionally, our findings facilitate the monitoring and assessment of disaster recovery and reconstruction by local and international non-governmental organizations and government agencies.

This study shows that apart from traditional approaches, there are also additional ways to monitor the level of reconstruction using less time and cost-intensive data and tools. The data that was used in our approach is openly available and can be accessed using the open-source tool overpass turbo in the case of OpenStreetMap and using the Flickr API in the case of the Flickr data. Likewise, the scripts that were used to access and process the data have been written in Python, an open-source programming language, and are available in the GIScience GitLab repository[16]. Using the presented data and scripts, our approach could be applied and replicated without additional cost in sense of data and software in other touristic places by updating and adjusting the bounding box in the overpass queries. Unlike Twitter and Facebook, Flickr is a picture based social media data platform, and therefore users of our approach do not have to mind linguistic restrictions. Adjusting the time in the provided scripts enables users to moreover adapt the assessed timeframe. The flexibility in terms of time and space enables users to benefit from this approach in different contexts and scenarios, also including other natural and man-made disasters. Before putting our approach in practice, the results could be furthermore validated using the discussed methods and tools and moreover using e.g. available tourism statistics and results of traditional approaches.

Presenting our approach and initial results to an international audience at conferences and the close cooperation of our project partners with tourism associations will enable raising awareness regarding this alternative approach for monitoring tourist activity and the level of reconstruction. This can also facilitate detecting potential beneficiaries who have to face challenges regarding lack of resources and professional expertise.

ACKNOWLEDGMENTS

This research is supported by Deutsche Forschungsgemeinschaft Initiative of Excellence, Heidelberg Karlsruhe Research Partnership (HEiKA) Program. We thank Karlsruhe Institute of Technology, Geophysical Institute for the partnership in conducting this research.

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[16] https://gitlab.com/giscience 19.3.2017.

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A situation model to support collaboration and decision-making inside crisis cells, in real time

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ABSTRACT

Natural and man-made hazards have many unexpected consequences that concern as many heterogeneous services. The GéNéPi project offers to support officials in addressing those events: its purpose is to support the collaboration in the field and the decision-making in the crisis cells.

To succeed, the GéNéPi system needs to be aware of the ongoing crisis developments. For now, its best chance is to benefit from the ever growing number of available data sources. One of its goals is, therefore, to learn how to manage numerous, heterogeneous, more or less reliable data, in order to interpret them, in time, for the officials. The result consists on a situation model in the shape of a common operational picture.

This paper describes every stage of modelling from the raw data selection, to the use of the situation model itself.

Keywords

Crisis Management, Situation Model, Situation Awareness, Big Data

INTRODUCTION

For the IFRC[1], the term "disaster" has a number of different meanings: it refers to natural hazards and man-made hazards, from floods to industrial accidents and terrorist attacks. Their consequences on the core networks compel governments to involve many actors in the crisis response. Each stakeholder comes with its own procedures, often not adaptable to current events or ongoing actions, but suitable for the crisis.

Because of the interferences due to the coexistence of so many responses, officials have to make all stakeholders collaborate. This calls for a deep knowledge of the ongoing situation, while the crisis cells are running out of time.

To help them, the GéNéPi project has been set up. It aims to support both their situation awareness and the needed collaboration. It also gives the crisis cells the opportunity to benefit from as many data sources as necessary. The problem is that the data, coming directly from unknown, unreliable, heterogeneous sources, are, for now, raw and unusable data. The GéNéPi project idea is to turn them into instances of a known, suited model. This will generate a new model illustrating the ongoing situation that will (i) offer situation awareness to

[1] IFRC: International Federation of Red Cross and Red Crescent Societies

the officials, (ii) enable the GéNéPi system to generate and (iii) maintain an accurate business response process.

The first part of this paper presents the current needs for a situation model, in a crisis context. The second part responds to a specific problem:

How to turn an evolving set of raw data into a model, suited to all officials, whatever their acting zone, within a limited time?

Finally, the third part describes the three main uses of the situation model, made possible by the interpretation of raw data during a crisis situation.

THE NEED FOR AN AGILE COLLABORATION INSIDE THE CRISIS CELLS

A crisis situation well known by the French people

"Then, it was a huge disaster; it was 4 o'clock at night; the river was still rising, people suddenly invaded in their home had to seek refuge in their attic which was hit before long." (Maistrasse and Wiart 1846)

One of the biggest fears French authorities have involves the Loire River: a mixed flood, due to both sea and oceanic rainfalls, would affect eight French counties, in less than ten days. In 1866, Gien, *6.717 inhabitants ("Des villages de Cassini aux communes d'aujourd'hui" 2007)*, knew a flow six hundred times higher than the regular flow. That year, 20% of the annual rainfall fell in three days and Jargeau, *2.578 inhabitants*, was devastated (Maison de Loire and DREAL 2011).

During the twentieth century no major flood happened in this area. According to experts, it is only a matter of time: the slopes, impermeable sub-grades and dikes of the area aggravate the risk of flood (Maison de Loire and DREAL 2011). And, when the water rises, will the authorities remember the past crisis and will they react quickly enough?

Many services involved in the crisis response

As widely acknowledged, the crisis management consists in four steps (Baldridge and Julius 1998) : the prevention, the preparation, the response and the recovery. This paper focuses on the preparation and response phases.

In France, a flood can be predicted two or three days ahead thanks to "Cristal" (DREAL 2010; Moulin and Thépot 1999). This official system provides hydrological models, meteorological radar images and reports aggregating information from diverse sources.

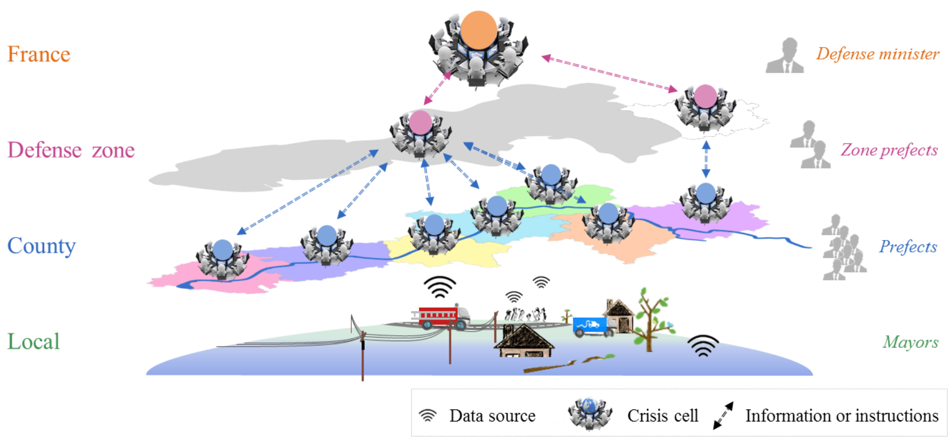

Figure 1 - Vertical granularity of crisis management in France

If needed, mayors will alert the population. They are in charge of the public safety and have to organize the response in their city, as the *prefects* for their county, the *zone prefects* for their defense zone and the *Defense Minister* in the country. Each of them sets up a crisis cell as soon as an alert is issued: they involve officials coming from the services, organizations and programs involved in the crisis response (cf. Figure 1).

A French law (Chirac et al. 2004) compels organizations; public, health and emergency services; medias; insurers; cities, counties, defense zones and ministries to prepare for potential crisis. But, when several plans apply, interferences happen. In order to avoid that, the crisis cells can make the stakeholders collaborate. Meaning that they have to (i) manage the different priorities, (ii) manage the communications and (iii) manage the network interdependencies, as well as make decisions and monitor the crisis situation.

The need for a situation model

Data represent the properties of objects and event, while information is deduced from them, as a description, an answer to simple questions like "who?", "what?" or "when?" (Ackoff 1989)

The GéNéPi project has been set up to support the crisis cells in making the stakeholders collaborate (cf. iii), in taking decisions (cf. i) and in following the crisis situation (cf. ii). Founded by a national agency, it gathers ten partners from academic researchers to industries and practitioners. The project, along with its system, is assessed once a year, by a steering committee that groups practitioners from all the middle Loire area. It offers to define, orchestrate and monitor the collaboration process: a set of coordinated actions executed by the stakeholders (cf. Figure 2**)**. To succeed, the project needs to be aware of:

- The stakeholders involved in the crisis response, their capabilities and the information that they can produce;
- The context, where the crisis struck;
- The ongoing developments due to the crisis.

This means that the GéNéPi system needs to collect data describing the partners, the environment and the events due to the crisis, and turn them into usable information. As a result, a model, called situation model, illustrates all the information deduced from a mining process (cf. Figure 2).

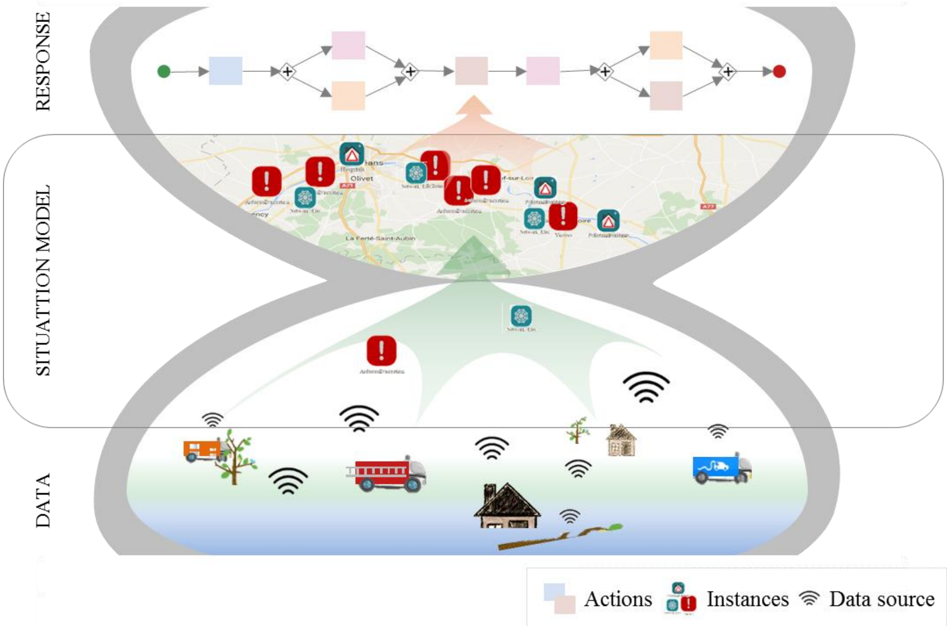

Figure 2 - The data and information life cycle imagined by the GéNéPi project's partners

The Information age as an opportunity

To describe and illustrate a flood, a lot of data describing the ongoing situation are needed. Hopefully, the electronic revolution and the digital age paved the way for a near-open access to real-time data.

The huge data volume and its variety

Many types of sources emit lots of heterogeneous data all the time (Gantz and Reinsel 2011; Ohlhorst 2012; Raghupathi and Raghupathi 2014) and during a crisis, such sources may be ordered by priority (Johansson 2015):

1. Official emergency management agencies: data coming from existing information system hosted by official services;
2. Official sectorial institutions : business information, known by some of the services involved in the response, can be communicated by phone, by e-mail, by walkie-talkies, by information systems and, even, by fax;

3. Relief or aid organizations: Information, as the one store in geographic information systems, can easily be updated by volunteers in near real-time: "Open street map" and "Google map marker" are widely used during crisis response (Ortmann et al. 2011);
4. Academic and scientific institutes: Histories of data are updated every day: for example, French floods are recorded in the BDHI[2] since the beginning of the 18th century;
5. Social media (not in Johansson but add here): Texts, audios, videos and images describing the consequences of the crisis are sent by ordinary people using, for example, Ushahidi or Twitter (Ortmann et al. 2011);

The speed necessary to process data in time

Such a tremendous data volume calls for high speed (Demchenko et al. 2013; Fayyad et al. 1996; Hashem et al. 2015; Kaisler et al. 2013): the system must be powerful enough to detect and integrate valuable data in time. For instance, a flow measure, which becomes irrelevant as soon as a new one arrives, has to be treated before the **expiry date** comes to an end.

The trust to put in data

All these sources cannot be trusted in the same way (Demchenko et al. 2013; Lukoianova and Rubin 2014; Rajaraman and Ullman 2012; Wu et al. 2014): some will be more or less biased, some not completely correct. For example, sensors have their own precision levels, journalists their own views, people their own beliefs, etc. Moreover, all these data travel from source to source, each one altering its original content.

THE GÉNÉPI INTERPRETER TO GENERATE A SUITED SITUATION MODEL, IN REAL TIME

In artificial intelligence, the GéNéPi system can be seen as an **agent** (Russell and Norvig 2009): it can perceive its environment, through the reception of **percepts**, and can act on the environment, through the orchestration of **coordinated actions**. As part of the GéNéPi project, the GéNéPi Interpreter[3] is responsible of the agent's situation awareness.

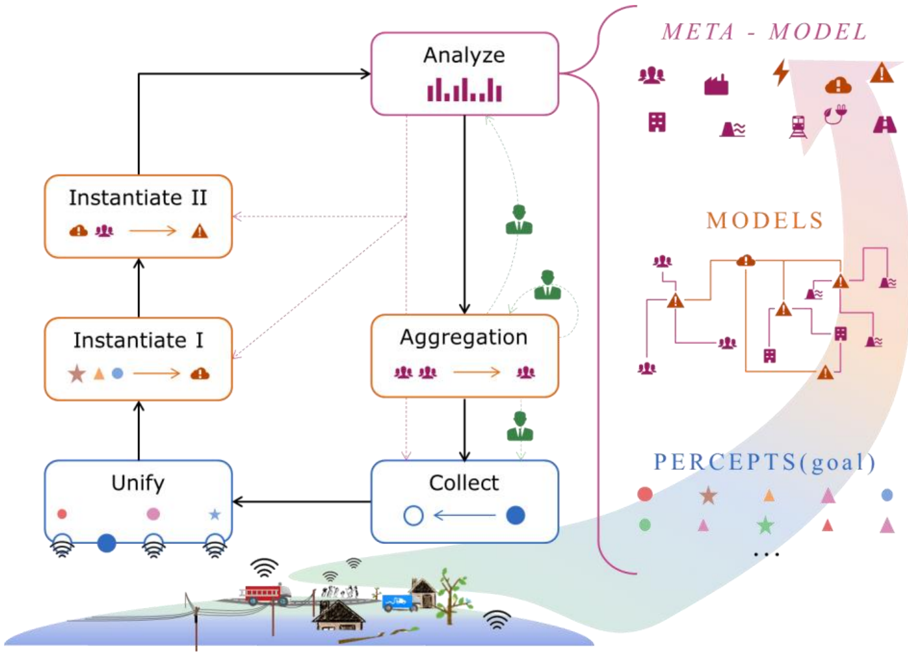

Figure 3 - The generation of a situation model that suits the decision-makers in a Big Data context

The GéNéPi Interpreter illustrates the ongoing crisis situation by instantiating a meta-model (common to all situation models). The *Meta-model* (Bénaben et al. 2016) is made of two types of concepts:

- *The first part of the Meta-model* can be instantiated mainly before the crisis, during the preparation

[2] French data base on floods, accessible at: http://bdhi.fr/appli/web/welcome

[3] The G. interpreter's real name was removed for blind review reasons.

phase. It concerns the capabilities of the stakeholders, willing to be involved or planned in a procedure, and the issues at stake in the area. Later on, during a crisis response, some unknown partners can emerge and new stakes can be identified: the model is completed along with the crisis developments.

- *The second part of the Meta-model* concerns the crisis itself: the danger, risks and events affecting the territory. An environment component is **hyper-vulnerable**, if the risk and its vulnerability to this risk are high (Anthony 1987).

For example, to represent the different hydrological regions of the Loire River, the system needs to list concepts (cf. Figure 4). There will be a watercourse, watercourse segments and dikes. Then, it will illustrate one region in particular by instantiating these concepts: for example, the "Loire River" passes through a city called "Orléans", located in the middle of the Val d'Orléans, and protected by a dike, called "Digue d'Orléans".

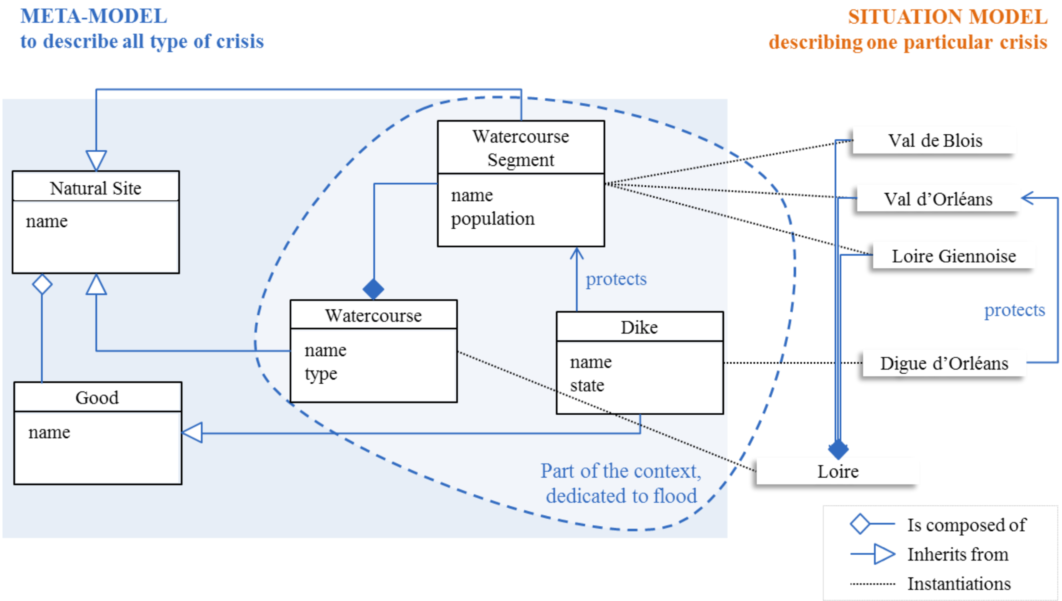

Figure 4 - The Meta-Model: a critical part of the Situation Model creation process

The goal of the GéNéPi Interpreter

The *Collect* module (cf. Figure 3) determines the goal of the Interpreter on a regular basis. It indicates which aspects of the environments are to be considered. The percepts – describing the crisis environment and perceived by the system – are thus, always suited to current priorities.

For example, at the beginning of the response, lower crisis cells try first to detect both the consequences and the risks due to the crisis. Thanks to them, upper crisis cells will be able to assess the magnitude of the crisis. In this case, the *Collect* module has to prioritize the collection of data that can be used to instantiate the *second part of the Meta-model*.

This function is critical (Endsley 1995) considering the amount of data to be processed in time.

The interoperability of all the Interpreter components

Data and information are received by the *Unify* module, under the *Collect* requirements. Information received from trusted, known sources can automatically be added to the situation model while the others are redirected to the *Instantiate* module (cf. Figure 3).

Inside the GéNéPi interpreter, issues soon arise due to the variety of data. This is one of the biggest obstacles to effectively make sense of a large data volume (Kaisler et al. 2013). To counter it, the *Unify* module automatically transforms the input data into XML[4] documents. These new data are **IT events**. They consist of: a date of creation, an ID, a topic, a geolocation and a description of the concerned **field events (cf.** Figure 5**).**

[4] Extensible Markup Language

From raw events to situation models

The *Instantiate* module aims to understand the meaning of the IT events: it links together disparate data to develop (Endsley 2015) the situation awareness of the system. This module is divided into two parts:

- *Instantiate I*, receives the events coming from the *Unify* module and turns them into instances of the *Meta-model.*
- *Instantiate II* deduces new instances directly from the situation model

When *Instantiate I* deduces a new flooding danger from the predicted evolution of the river, *Instantiate II* adds a new risk for each sensitive building threaten in the area (a danger brings risks on each stake in its perimeter). For example: a risk of victim will emerge for each household vulnerable to the flood; a risk of drop in power supply if a transformer is located in a flood area; etc.

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
        xmlns="http://www.mines-albi.fr/loireFloodingEvent"
targetNamespace="http://www.mines-albi.fr/loireFloodingEvent"
        elementFormDefault="qualified">

        <xsd:element name="Event_ForecastMeasures">
                <xsd:complexType>
                        <xsd:sequence>
                                <xsd:element ref="Measures_ForecastMeasures" minOccurs="0"
                                        maxOccurs="unbounded" />
                        </xsd:sequence>
                </xsd:complexType>
        </xsd:element>

        <xsd:element name="Measures_ForecastMeasures">
                <xsd:complexType>
                        <xsd:sequence>
                                <xsd:element name="id" type="xsd:string" />
                                <xsd:element name="stationName" type="xsd:string" />
                                <xsd:element name="stationLat" type="xsd:float" />
                                <xsd:element name="stationLong" type="xsd:float" />
                                <xsd:element name="f_min" type="xsd:float" />
                                <xsd:element name="f_med" type="xsd:float" />
                                <xsd:element name="f_max" type="xsd:float" />
                                <xsd:element name="wl_min" type="xsd:float" />
                                <xsd:element name="wl_med" type="xsd:float" />
                                <xsd:element name="wl_max" type="xsd:float" />
                                <xsd:element name="date" type="xsd:dateTime" />
                                <xsd:element name="nbHours" type="xsd:string" />
                        </xsd:sequence>
                </xsd:complexType>
        </xsd:element>

</xsd:schema>
```

Figure 5 – XSD of the hydrological events simulated by the GéNéPi system, sent each day by the SPC (the French flood forecast service). There is one measure for each forecast and 54 hours of forecasts per event.

The monitoring of the Interpreter

One goal of the *Analyze* module is to forecast the future, in the shape of a new model, derived from the situation model. This model, called **projected model**, is produced by mixing the response process (cf. Figure 2), the predictable **natural progressions** of the crisis and the situation model together.

The 48h projected model can, for example, take into account: the evolution of water level and water flow, forecasted by the SPC (cf. Figure 5) or the fact that the risk of victim will be prevented thanks to an evacuation to be. 48h from now, the crisis cells will be able to compare this projected, expected model to the situation model updated in real-time. If the expectations did not suit to the reality, the crisis cells must adapt the on-going response (cf. Figure 7).

The other goal of the *Analyse* module is to monitor the **quality** (Wang and Strong 1996) of the percepts, of the models and of the *Meta-Model* (cf. Figure 3). To succeed, it looks for data in the whole system, in order to confirm findings, fill missing information or improve the veracity of the models. These iterations also enable the *Analyse* module to alert the administrator when one source or one operating rule is to be seriously questioned.

The users' point of view

The models contain so much information that the user needs to focus in terms of both granularity and scope. For example, instead of the name, function and geolocation of each potential victim, the crisis cell of the defense zone (cf. Figure 1) would prefer a quantity per county. However, a prefect would choose the other option.

The *Aggregate* module has been set up to adjust, in real-time, the models to each crisis cell. For the Loire River flood, this represents nine different points of view, from three main categories: county crisis cells, zonal crisis cells and national crisis cell (cf. Figure 1).

This module also deals with the rights and wills of officials. For instance, a crisis cell from the defense zone might want to know further details about a particular event resulting from the crisis. And, if this information has been classified by the national level, a formal authorization will be required.

THE SITUATION MODEL TO SUPPORT THE DECISION MAKERS

A common operational picture inside each crisis cell

The *Aggregate* module provides a common operational picture adapted to the expectations of each crisis cells. Once displayed, it illustrates both the situation and projected models with a point of view that fits the expectations of those present. The goal (Endsley 2015; Kaisler et al. 2013) is to provide with answers to "what is happening?" and "what is likely to happen next?", as fast as possible.

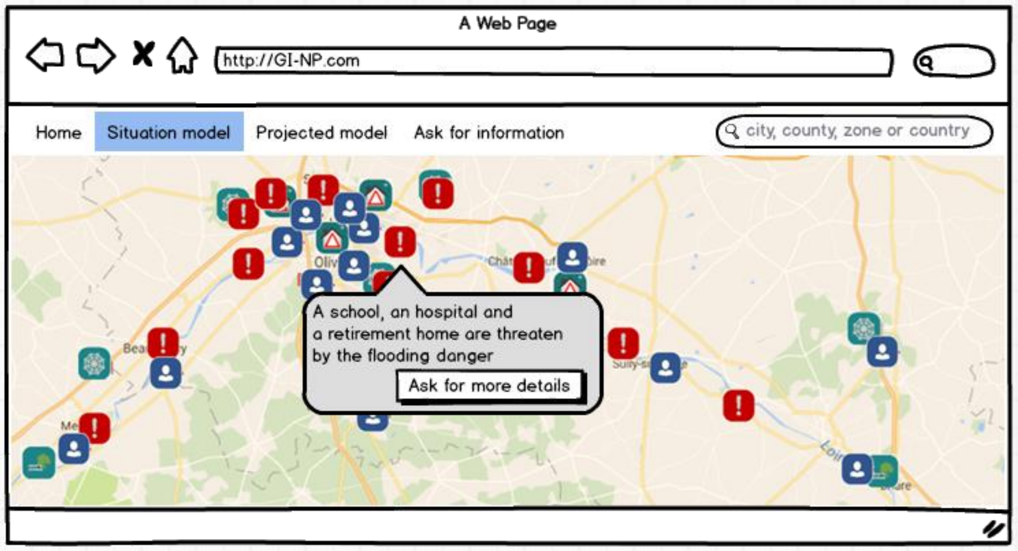

Figure 6 - Mockup of the future user interface, displaying the situation model

The common operational picture also significantly reduces the uncertainties and stress related to decision-making (Dautun and Lacroix 2013). The picture is displayed in a shape familiar to the stakeholders: a GIS[5] interface (cf. Figure 6).

A support to collaboration for the stakeholders involved in the response

The GéNéPi system uses the situation model to choose and coordinate the actions relevant to the response. The goal is to support the collaboration of the stakeholders in the field, to free up the decision-makers time. To succeed, it needs information on the available stakeholders and the element of context impacted by a risk, a danger or a consequence of the crisis. That's why, the GéNéPi *Meta-model* (cf. the example in Figure 4) covers these three parts: it ensures the completeness of both the projected and situation models.

The agility of the collaboration offered to the stakeholders

The response process, conversely to the models, cannot be updated in real time: it would require too much time. The idea is to detect the most suitable moment to launch an adaptation of the response process. In order to do that, the situation model is compared to the model, projected for this moment (cf. Figure 7). The distance between the two models is computed considering the importance and cost of the differences (Barthe-Delanoë et al. 2014). If the distance exceeds a threshold, a new response process is deduced.

[5] Geographic Information System

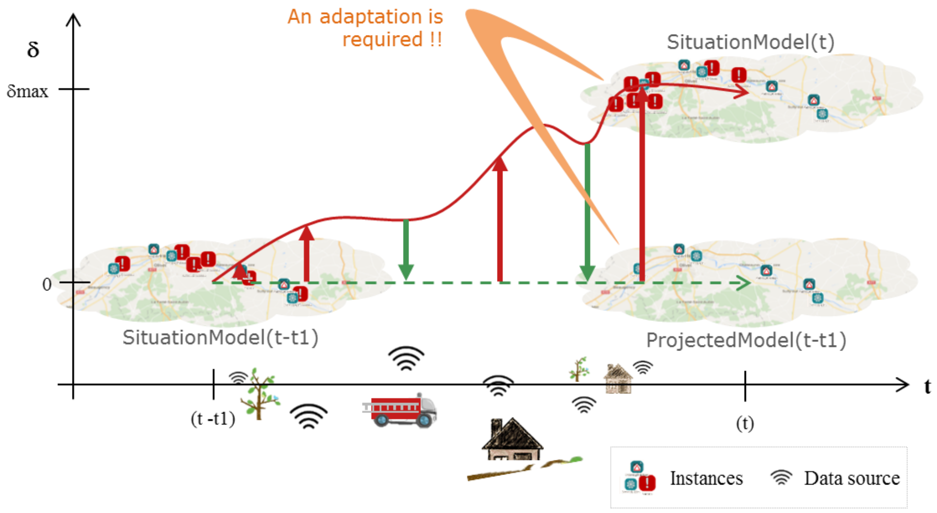

Figure 7 - Illustration of how the agility is computed in the *GÉNÉPI Interpreter*

CONCLUSION

Officials involved in a crisis response do not have time for taking new data sources into account, while it is the opportunity to take well-informed decisions. To support them the GéNéPi project offers to both support the collaboration of the stakeholders in the field, and the data management in the crisis cells.

The GéNéPi Interpreter, introduced in this paper, is a part of the GéNéPi system. It is dedicated to the collect, the interpretation and the use of raw data coming from trusted, available sources.

At the end of 2017, the GéNéPi system will be used for the first time in public. In 2018, several new scenarios will be tested. After the end of the project, the two PhD students of the GéNéPi project will continue to develop the different parts of the solution, including the GéNéPi Interpreter, and several new projects should take over the work next years.

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Future Trends

Thumbs up? Attitudes of Emergency Managers to Proposed Masters Programs in EM With an IS Focus

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ABSTRACT

Information Systems (IS) increasingly are used in Emergency Management (EM), so it is prudent to include IS study in EM education. This paper presents the results of analyzing the responses to a survey that proposed potential courses for programs at the master's level. The survey was completed by 373 practitioners, academics and/or researchers with EM experience. All proposed courses were rated above 4 on a 7-point scale for how essential they are to the curriculum. However, there were disagreements. Qualitative analysis of volunteered comments indicate that some low ratings were due to disagreement with the content of the course as described, or with the need for an entire course to cover the topic. An unexpected finding was that a substantial number of respondents spontaneously expressed opposition to the use of IS for EM in general. The findings are discussed and a preliminary curriculum is proposed.

KEYWORDS

Emergency Management Education; Master's curricula;

INTRODUCTION

Emergency management (EM) is a crucial and growing profession, thus it is important that higher education institutions provide degree programs that will prepare students to take responsible positions in the field. Since the terrorist attacks of September 11, 2001 in the USA and in other places such as London and Paris, governments worldwide have invested considerable resources in the writing of emergency response plans and the training of emergency responders. In addition, climate change has produced an increase in natural disasters, necessitating further planning and response activities from emergency managers. Particularly in the United States, the federal government has created new homeland security organizations and urged state and local governments to appoint official emergency response agencies and draw up plans for a variety of disaster scenarios (Perry and Lindell, 2003). In Europe, the DITAC (Disaster Training Curriculum) project has identified deficiencies in current responder training approaches and analyzed the characteristics and content required for a new, standardized European course in disaster management and emergencies (Manesh-Khorram et al. 2015).

As Lucus-McEwen (2011) points out, "Emergency management … is projected to continue growing at a rate of 20 percent or more." That growth is reflected in the large and increasing number of higher education programs offering degrees or certificates in emergency management (http://www.training.fema.gov/hiedu/collegelist). There are more undergraduate programs listed in Emergency Management (50) than master's programs (42 as of December 2016). In addition to the EM master's degrees, there were 44 masters' programs listed in the related field of Homeland Security. When one looks at the curricula for the degrees, there are generally few, if any, courses in Information Systems, even in the Homeland Security programs which one would think would include cyber-security. Given that technology is becoming more ubiquitously used in emergency management, this is a gap that needs to be addressed.

There have been calls for standard curricula guidelines for EM for some time. For instance, Alexander (2003) discussed the possible future role of standards in assuring the quality and content of programs for educating and training people in the fields of emergency planning and management. Due to the complex and multi- disciplinary nature of EM, it has been a challenge for higher education institutions to incorporate all the necessary knowledge within the curriculum (Perdikou et al., 2014). A second identified challenge is a lack of flexibility of formal education institutions to provide rapid responses to the dynamic requirements of practitioners and EM organizations, and to their need for continued lifelong learning (Thayaparan et al., 2015).

As active participants in the more than decade-old ISCRAM association (Information Systems for Crisis Response and Management), the authors' premise is that knowledge and use of information systems is a key part of emergency management today and in the future, and ought to be included in masters' programs (Turoff, 2014). Therefore, with the support of ISCRAM, an education committee was formed and subsequently designed and carried out a survey of EM scholars and practitioners aimed at developing master's level curricula for EM in general, and for Information Systems (IS) master's programs with a concentration in EM. To our knowledge, this is the first investigation into which IS courses need to be included in master's level EM programs. The first round of circulation of the survey went to participants in the ISCRAM 2015 conference, and others to whom they may have passed on the link. The preliminary quantitative results of that survey, with 111 respondents, were presented at ISCRAM 2016 (Plotnick et al., 2016). Subsequently, with the cooperation of IAEM (the International Association of Emergency Managers), the invitation to participate was circulated much more widely, resulting in 373 total responses, including many more responses from practitioners. Many of the questions had comment boxes as well as fixed responses. A preliminary look at some of the themes raised in these comments appeared in (Turoff et al., 2017). This paper presents a comprehensive overview of the final quantitative and qualitative results of the study.

After reviewing the methods employed, we present first, the final quantitative results of the survey, including an exploration of characteristics of respondents that were related to differences of opinion on courses in the suggested curricula. Next, we discuss the results of a rigorous content analysis of free text responses for four of the courses. In addition, we provide examples of an unanticipated result that surfaced spontaneously in text comments to a variety of questions: the importance of any place in EM for Information Systems. The paper ends with a Discussion and Conclusions section, including limitations of the study and suggested future research.

METHOD

Higher Education (university) programs may have one or more foci (e.g. general study, policy). The survey had questions about general EM courses that should be included in all EM programs (*general EM courses for all EM programs category)*, regardless of the program focus; courses related to IS in EM that would be included in programs for which a focus is EMIS (*EMIS courses for programs focused on IS for EM* category), and courses related to IS in EM that would be included in all programs not focused on IS for EM (*EMIS courses for all EM programs* category). The survey included rating scale questions with descriptions of proposed courses for the curriculum (courses to be included in the EM program), placed in the three categories, for which the respondent was asked to rate the course on a scale from 1 (should not be in the curriculum) to 7 (essential to the curriculum). Each course in the general EM category and EMIS courses for programs focused on IS had an open-ended question for respondent comments following the rating scale item. Additional open-ended questions were available to respondents to comment on each category of courses and the research. Demographic data were also collected through nominal question items. The complete list of courses and descriptions is in Appendix A.

An initial deployment of the survey resulted in 110 usable responses. The description of the participant recruitment method, participants, and quantitative analysis of the rating scale question responses is reported in (Plotnick et al., 2016). After further distribution of the survey the total number of responses increased to 558. The data for respondents who just began the survey but terminated it before answering any questions were deleted from the analysis. This resulted in a total data set of responses from 373 participants. Turoff et al. (2017), in their review of comments, note that the full data set of 373 were responses from a more diverse group of respondents than represented by the initial set of respondents.

This paper reports on results of quantitative analysis of the full set of quantitative data (semantic differential item responses) using SPSS 24®, and a systematic content analysis of selected qualitative data (responses to open-ended questions) using the online coding application Dedoose (dedoose.com). For the quantitative data analysis, tests included: tests of normality of continuous data, means, frequencies, and nonparametric tests (Mann-Whitney U, Kruskal Wallis) to determine the statistical significance of differences. Nonparametric tests were used because the data were not normally distributed. For the qualitative data analysis, initially axial coding was used and then open-coding. First, a set of codes was developed based upon the focus of questions, the quantitative results, and review of the comments described in (Turoff et al., 2017). A “thought” (which could be a phrase, a sentence, or multiple sentences as long as the segment represented a single thought) was used as the unit of coding. For example, the single word response of “elective” was determined to constitute a thought, as was the phrase, “This is the future”, the sentence, “Media management is a minimal part of the EM curricula”, and the multi-sentence paragraph, “Simply put, SM is not going away any time soon. In order to control the misinformation that is put out there on SM, we have to buy into the program, plain and simple.”.

Consistency in coding between the different researchers was ensured by working jointly on comments, renaming codes to ensure clarity, and cross-checking coding results by calculating the intercoder reliability measure. Once adequate inter-coder reliability was established (first measured at under .5, finally measured at .78), the passages were divided between the researchers for coding.

RESULTS OF THE QUANTITATIVE DATA ANALYSIS

Characteristics of the Survey Respondents

Demographic information was collected from the respondents about the number of years the respondent has worked as a practitioner, academic, and/or researcher; the highest academic degree earned; the country in which the respondent has done most of his/her EM work; and whether the respondent is a member of an EM association (IAEM, ISCRAM, TIEMS, and/or other). Not all respondents answered all questions. Almost half of those who answered the question about academic degree (42%) hold a master’s degree, but not a doctorate, and 18% have earned a doctorate. Fifty-four percent of the respondents belong to at least one professional organization. The highest frequency was for membership in an organization other than the ones noted in the survey (295). For the organizations listed in the survey, the highest frequency was for membership in IAEM (169) followed by TIEMS (22) and ISCRAM (16). The “other” organizations were diverse and included international, regional and state organizations. Many of the respondents are members of more than one professional organization.

The diversity of respondents is also clear from the demographic data regarding primary location and types of EM work. 266 respondents reported at least some experience as a practitioner; 143 have had experience in academia; and 128 have had research experience. Over half of the respondents who indicated years of work as a practitioner, academic, and/or researcher (57%) have, in their careers, served in more than one of those roles. The primary professional location is mostly in the United States (60%).

From these results, we conclude that our respondents are well-educated, active in the EM domain, represent international perspectives on EM, and have engaged in a diverse set of professional EM activities.

Ratings of Courses

Means were taken for ratings (from 1 – should not be in the curriculum, to 7 – essential to the curriculum) of each course (see Tables 1 through 3 below). Responses of “no opinion” were not included in the analysis.

GENERAL EM COURSES FOR ALL PROGRAMS			
Course	**N**	**Mean**	**Std. Deviation**
Professional Characteristics and Organizational Practices for EM	367	6.41	1.02
Planning Foresight, and Risk Analysis and difficulties of the recovery effort	369	6.31	1.12
Case Studies of Failures in Emergency Management	369	6.26	1.14
Disaster Types and Characteristics	370	6.11	1.30
Critical Infrastructures and Their Interactions	368	6.07	1.18
Legal, Ethical, and Policy Concerns	371	6.02	1.24
Security and Terrorism Characteristics and Situations	368	5.40	1.44
Public Health and Medical Services	367	5.38	1.47
Emergencies in Developing Countries	365	4.77	1.58
Fire Fighting Characteristics and Situations	365	4.25	1.74

Table 1. Ratings of general EM courses for all EM programs

EMIS COURSES FOR PROGRAMS FOCUSED ON INFORMATION SYSTEMS IN EM			
Course	**N**	**Mean**	**Std. Deviation**
Social Media for EMIS	344	5.89	1.33
Decision Support Systems for Emergency Management	339	5.75	1.45
Requirements for Emergency Management Information Systems (EMIS)	336	5.61	1.44
Collaborative Problem Solving Using EMIS	340	5.50	1.50
A Master's Thesis	333	5.44	1.63
Advanced Topics in IS for EM	334	5.38	1.56
Participatory Databases for EMIS	339	5.27	1.50
Information Systems Evaluation	333	5.17	1.54
Human Computer Interface (HCI) Design for EMIS	336	5.10	1.59
Sensor and Network Systems for EMIS	333	5.02	1.53

Table 2. Ratings of EMIS courses for programs focusing on information systems for EM

EMIS COURSES FOR ALL EM PROGRAMS			
Course	**N**	**Mean**	**Std. Deviation**
Social Media for EMIS	313	5.57	1.48
Collaborative Problem Solving Using EMIS	311	5.30	1.45
Decision Support Systems for Emergency Management	308	5.28	1.50
Requirements for Emergency Management Information Systems (EMIS)	310	5.07	1.62
Advanced Topics in IS for EM	310	4.97	1.65
Participatory Databases for EMIS	310	4.88	1.57
Digitizing a paper world	311	4.84	1.70
Information Systems Evaluation	310	4.75	1.65
Sensor and Network Systems for EMIS	310	4.63	1.61
Human Computer Interface (HCI) Design for EMIS	309	4.59	1.66

Table 3. Ratings of EMIS courses all EM programs

All the courses in the categories of *General EM* courses and *EMIS courses for IS focused programs* were highly rated ($\mu>5$) as being essential to the curriculum. While there were no courses in the *EMIS courses for all EM programs* category that had means below 4 on the 7-point scale, there were several courses that were rated between 4 and 5. This result is notable and is explored in the qualitative data analysis described later in the paper. Although the larger data set analyzed here were results from a more diverse set of respondents, the top-rated courses in each category are the same as those rated most essential by the initial group of respondents (Plotnick et al., 2016). This suggests that all proposed courses are valuable for EM students pursuing a diverse set of professional careers. The top four rated courses in both the *EMIS courses for IS focused programs* and the *EMIS courses for all programs* were the same, albeit not in the same rank order. This suggests that these four are core IS courses for any program.

Next, we report on the results of testing whether the ratings are significantly different based upon respondent characteristics. The .05 level of significance was used to identify significant results.

Comparison of ratings by respondent role

We have noted that most respondents have, in their careers, acted in more than one EM role (practitioner, academic, researcher). Whether role differences affected perceptions of how essential courses are was assessed first by asking if the respondent had any experience as a practitioner, and then by the range of roles reported. Most the respondents (N=266) reported that they had some experience as a practitioner. Therefore, we tested, using Mann-Whitney U tests, whether there was a significant difference in course ratings by those with practitioner experience, and those without it. There was a significant difference for two courses: Collaborative Problem Solving in the category of courses for IS focused EM programs ($z=-2.1$, $p=.035$) and HCI for all EM programs ($z= -1.99$, $p = .047$). For these two courses, the respondents without practitioner experience rated the course as significantly more essential than did the respondents with practitioner experience.

Since many respondents have served in multiple roles, a finer grained analysis was then performed. Three hundred of the respondents reported the number of years they served as a Practitioner ($\mu = 14.25$), Academic ($\mu = 8.08$) and Researcher ($\mu = 7.4$). The distribution across those roles is shown in Table 4 below.

ROLE	FREQUENCY
Practitioner Only	113
Academic Only	3
Researcher Only	13
Practitioner & Academic	52
Practitioner & Researcher	34
Academic and Researcher	19
Practitioner, Academic, & Researcher	66

Table 4. Frequencies of respondent reported roles

Grouping responses by the 7 role combinations shown in Table 4 and comparing the ratings of the groups (Kruskal-Wallis tests) did not uncover any statistical differences in course ratings. The results of the two approaches suggest that, in general, respondents with diverse types of EM experience similarly perceive the importance of the courses. Where there are differences, the critical factor is whether the respondent has had experience as a practitioner.

Comparison of ratings by highest degree earned

Kruskal-Wallis tests were performed to assess whether the ratings of courses differed by the highest degree earned by the respondent. For courses in the *General Courses for EM* category, two significant differences were found: Fire Fighting Characteristics and Situations was rated significantly more essential by those with Associates (2-year undergraduate) degrees than by those with Masters Degrees (X^2 = 18.18. p = .003) and Security and Terrorism Characteristics and Situations (X^2 = 13.44, p = .02) was rated as significantly more essential by those with Bachelor's Degrees than by those with Doctoral Degrees. There were no significant differences by highest degree earned in ratings of courses in the *EMIS courses for IS focused programs* category. One course in the *EMIS courses for all EM programs* category was rated significantly differently by respondents with different levels of education: Digitizing a Paper World (X^2 = 18.72, p = .002) was rated significantly more essential by respondents with Bachelor's Degrees than by those with Doctoral degrees and significantly more essential by those with Masters Degrees than those with Doctoral degrees. The Kruskal-Wallis test did not indicate significant differences for this course between other comparisons of groups (e.g. Bachelors vs. Masters).

In summary, there were few differences by degrees, suggesting that the level of respondent education has little to no effect on perceptions of the need for the proposed courses.

Differences in ratings by the number of years' experience in a role

Means were calculated for the number of years of experience in the each of the roles: practitioner, academic, and researcher. Respondents were separated into two groups (Less Experience and More Experience groups) for each of the roles of practitioner, academic, and researcher such that the Less Experience group had years of experience below the mean and the More Experience group had years' experience at or above the mean. Course ratings then were compared (Mann Whitney U tests) for the two groups for each role. There were only two courses for which any significant differences were found. In the *General EM Courses* category, the Professional Characteristics and Organizational Practices for EM course (z = -2.57, p = .01) was significantly rated as more essential to the program by respondents with more experience in academia than by those with less experience in academia. In the *EMIS courses for all EM programs* category of courses, the Collaborative Problem Solving course (z = -2.046, p = .041) was perceived as significantly more essential by those with more academic experience than by those with less academic experience.

In summary, across all proposed courses, neither role nor the number of years the respondent has been in the EM discipline is an important factor in forming perceptions of the usefulness of the proposed courses.

Differences in ratings by primary location of EM activity

The respondents were a diverse global group of EM professionals. For analysis, we separated the respondents into four groups: U.S., English Speaking British Commonwealth, Other Europe, and Other. Kruskal-Wallis tests were performed to ascertain if there were significant differences in the course ratings by those groups.

For the ratings of courses in the *General EM courses* category, four courses were found to have significantly different ratings by groups: Planning, Foresight, and Risk Analysis (X^2=9.89, p=.02), Public Health and Medical Services (X^2= 22.82, p <.001), Security and Terrorism Characteristics and Situations (X^2=25.51, p <.001), and Emergencies in Developing Countries (X^2 = 9.07, p = .028). Non-parametric Kruskal-Wallis tests do not show where the differences lie when they are detected. Therefore, we then ran ANOVA tests with Tukey's Post-Hoc tests. However, ANOVA, a parametric test, is less sensitive on data that are not normally distributed, so may not detect significant differences that do exist (and are detected by the non-parametric tests). The ANOVA tests did not detect the differences for two of the above-mentioned courses: Planning, Foresight, and Risk Analysis and Emergencies in Developing Countries. However, the tests revealed significant differences by groups for the other two courses. The Public Health and Medical Services course was rated as more essential by U.S. respondents than respondents from English Speaking British Commonwealth countries; the respondents in the Other group rated it more essential than those in the Other Europe group; and respondents in the Other group rated it as more essential than respondents in the English Speaking British Commonwealth group. Other group comparisons (e.g. Other vs. U.S.) were not revealed to have significantly different ratings.

The Kruskal-Wallis tests detected significant differences in ratings by country group for three courses in the *EMIS courses for IS focused programs* category: Decision Support Systems for Emergency Management (X^2 = 9.42, p = .024), Sensor and Network Systems for EMIS (X^2 = 8.70, p = .034), and A Master's Thesis (X^2 = 10.43, p = .015). Anova tests did not detect these differences. Note that this does not suggest that there are no significant differences, just that we cannot determine where the differences lie.

Tests by grouping of the courses in the *EMIS courses for all EM programs* category revealed significant differences for five courses: Decision Support Systems for Emergency Management (X^2 = 12.05, p = .007), Sensor and Network Systems for EMIS (X^2 = 15.65, p = .001), Participatory Databases for EMIS (X^2 = 12.44, p = .006), Information Systems Evaluation (X^2 = 10.59, p = .014), and Digitizing a Paper World (X^2 = 8.17, p = .043). For the course, Decision Support Systems for Emergency Management, ANOVA detected a significant difference (F = 2.82, p = .039) but the Tukey's Post-Hoc test did not reveal where the difference lay. The ratings of the Sensor and Network Systems for EMIS course were significantly higher for the Other group than the U.S. group and significantly higher for the Other group than the English Speaking British Commonwealth group. The Participatory Databases for EMIS was similarly rated higher by the Other group than the U.S. group and rated higher by the Other group than the Other Europe group. The ANOVA tests did not detect significant differences in ratings by group for the other two courses.

To summarize, there are differences among groups of countries related to several of the courses. However, our sample sizes for countries other than the U.S. are not large enough to identify consistent patterns in these differences.

RESULTS OF THE QUALITATIVE DATA ANALYSIS

Qualitative analysis of comments of selected course data

Space was provided for respondents to comment on courses in two of the course categories. We content coded the comments associated with the highest and lowest rated courses in each category. The highest rated course in the *General EM Courses* category was Professional Characteristics and Organizational Practices for EM (μ = 6.41), while the lowest rated course was Fire Fighting Characteristics and Situations (μ=4.25). In the *EMIS Courses for IS-Focused Programs* category, the highest rated course was Social Media for EM (μ=5.89) and the lowest rated course was Sensor and Network Systems for EMIS (μ=5.02). Table 5 shows the frequency count for each code as applied to "thoughts" in the comments for each course. Note that some code segments ("thoughts") may have more than one code applied to them. Therefore, the totals of codes applied in a course may not be equal to the number of "thoughts" coded.

	Fire Fighting N = 88	Professional Characteristics N = 60	Social Media N = 36	Sensor and Network Systems N = 23	TOTAL
Ambivalent about course	2	1	1	0	4
Content or course focus	22	26	8	5	61
Dismissive (subcode of negative about the course)	1	0	0	0	1
Elective	18	0	3	4	25
Include content in other course	17	6	4	1	28
Negative about course	4	2	2	1	9
Negative about IS	0	0	1	2	3
Not relevant - do not include course	19	1	0	2	22
Offer to undergrads only	1	3	0	1	5
Other	3	1	0	0	4
Overall Curriculum Consideration (general comment about EM programs)	0	4	2	0	6
Positive about course	4	12	15	6	37
Positive about IS	0	0	1	3	4
Required	1	4	4	0	9
Survey Feedback	0	1	0	0	1
Totals	92	61	41	25	219

Table 5. Frequency of Application of Codes (N = number of "thoughts" per course coded)

For the **Professional Characteristics and Organizational Practices for EM** course, the respondents had many suggestions about what content should include. A sampling of comments is:

- *This is important to understand the organizational set up in a specific country …..*
- *A key aspect would be the inter-organizational collaboration.*
- *Will be important to emphasize the difference between emergency responders and emergency managers*
- *Good to offer the breadth of possible EM positions.*

That the course was well received (highly rated) is echoed in comments such as:

- *This is the key to effective EM.*
- *An understanding of this is necessary for all EM students*
- *To omit this would seem inconceivable*
- *I would consider this to be a core topic in any EM master's curriculum.*

However, there were a few comments that suggested that the content should already be known by Master's level students, underscoring the need to develop entrance criteria for a graduate level program. E.g.:

- *At the Bachelor's and Certificate [non-degree] levels this may be appropriate*
- *At the Master's level this basic understanding should already be in place*

Fire Fighting Characteristics and Situation was the lowest rated course in the *General EM Courses* category. While some respondents thought that it would be valuable "to provide overview for EMs" and that "A basic understanding of this is necessary for all EM students", many more respondents had concerns that it should not be included in an EM program because, as one respondent who had experience as a Practitioner and as a Researcher, put it, "Fire-fighting is NOT EM". A sampling of similar concerns includes:

- *Fire-fighting is a specific skill and not needed in an emergency management degree.*
- *Better added to a Fire Academy curriculum*
- *Emergency managers or planners are not firefighters*
- *Not something the PEM [professional emergency manager] needs to know*
- *Why? Isn't this degree set at a higher, broader, more strategic-level than fire-fighting?*

One respondent was dismissive in commenting, "You can define fire types (and resources) in a 2-page pamphlet." Yet, some respondents did see value in the course content proposed. The 18 suggestions that it be offered as an elective included: "Great elective, but not essential to the core component of an emergency manager." and "Really only where the student intends to take a fire focus in their career". Others suggested that, in an EM program, it could be covered as part of another course (e.g.: "Not an entire course. Maybe a couple of chapters."). Yet respondents who generally rated the course highly had positive comments about the course and suggested additional content (e.g.: "Especially talk about wildfires." and "The focus of this course should be on how Emergency Managers 'interact' with firefighters …"). The disparate perceptions of respondents to this course may be explained, in part, by a respondent with experience both as a Practitioner and Researcher: "*The fire service is an all-hazards response entity that has, in my opinion, not been fully integrated into the EM community. Fire department response capabilities need to be seriously addressed …".*

The responses to this course suggest that, when developing curricula, the scope of the curricula and a working definition of EM must be first defined.

Social Media for EM was the highest rated course in the *EMIS Courses for IS-Focused Programs* category**.** Respondents noted that Social Media is an important topic for emergency managers and is essential to the curriculum. A sampling of comments is:

- *A must have*
- *Currently a driving context for EM*
- *Absolutely essential*
- *Social media will either make or break an EM organization. Very important to have training in this.*
- *There is nothing worse than seeing a county fail to utilize Social Media during crisis. It's low hanging fruit.*
- *The wave of the future*

However, there were concerns about both the inclusion of the course and the use of Social Media in EM. Some respondents noted that, while Social Media is needed in emergency management, the emergency manager would not be the one managing the platform and so the course as described (an EMIS course) should instead focus more on policy and use rather than the technical aspects (e.g. That using Social Media is important even though the emergency manager may not actually be the one to access it, and a suggestion that the course should be included as a general EM course and focus less on the technical aspects and more on the policies). However, generally the comments were positive about the course. There were recommendations made that included having a more general communications course in which Social Media is a topic or offering the course as an elective. Suggestions included making certain that content addressed concerns about "How to use/how to control/ how to restrict the disclosure of privacy or sensitive information…" and how to contend with false information

Thus, there is general agreement that the importance of Social Media in emergency management is growing with some concerns about who in the EM domain needs to study the topic, and what topics are necessary for the course. This, again, is an issue of defining scope.

Sensor and Network Systems for EMIS was the lowest rated course in the *EMIS Courses for IS-Focused Programs* category. There were positive comments (e.g. "Now this has potential", "This is very important") and some suggestions that it be offered only as an elective "for those interested in designing systems" or as an important course "if Information Systems is the focus of the program". This course did provoke several comments that were negative about IS (e.g. "Don't rely on technologies"). A few recommendations for content were made: "This course needs to discuss the reality of IS in disasters …" and "Sensor is important, but really look at teaching how network protocols work, new technology in this area, and how it changes the fundamentals of disaster IS design [sic]", and "This could be more than sensors and field devices. It could be considered [as] non-traditional devices, including automated aerial vehicles (drones)".

The Elephant in the Room: Attitudes towards IS in EM

We did not have an explicit question about whether Information Systems courses should be included in masters' level curricula to prepare Emergency Managers. We had just assumed that "everybody" would share our conviction that now and in the future, EMs would need to have substantial understanding of IS and their application in their profession. However, although there was no specific question on this topic, participants voiced opinions that were negative or positive about IS in general in response to many different questions that were nominally about a specific course or another topic. Overall, there were 33 comments that were positive about IS in general, and 47 that were negative.

Looking first at the positive comments, they tend to echo our own pre-suppositions, e.g.:

- *Computer and internet based support make the emergency efforts and activities far more effective, smooth and swift.*
- *Computer systems are improving on an exponential scale for use and capabilities. Computers and systems are ubiquitous to society and therefore their use must be figured into emergency management programs.*
- *Essential - this element is only going to get stronger in EM practice.*
- *With advancements in technology this is very important for the educational process.*
- *Without IS no emergency efforts can totally be fruitful and effective*.

The total number of positive comments made about IS in general were about evenly divided between those who were practitioners only (16) and those who had other roles or a combination of practitioner and academic and/or research roles.

Looking at the negative comments, there are two main themes that emerge: distrust in the reliability of computer systems, and a dismissive attitude towards the use of computers rather than relying on human skills; sometimes these themes overlap.

Here are some examples of a lack of trust in being able to count on the use of IS during emergencies:

- *While this is good for more efficient management, during disasters, many Emergency Management Information Systems fail to function as designed and EMs must revert to manual systems to function. How would an emergency manager and the EM program operate when these systems aren't functioning?*
- *Computers are great until it's T+60 and your generator is out. Learn paper & pencil!*
- *The problem with computers in a disaster is that they do not always work and to concentrate on them solely is doing no good.*

There were far more comments about the second theme, which is a dismissive attitude towards computer systems in general and an opinion that the emphasis in training should be on human thinking and decision making:

- *Don't rely on technologies. Boots on the ground are always better for accurate information.*
- *Needs to emphasize the human decision-making element with IS as an enhancement thereof.*
- *…while a nice convenience to have in response, it should never become a critical need placed over effective training, situational awareness or critical thinking.*
- *Don't over emphasize computer systems. They are only a tool. Make sure they know the paper and pencil systems.*
- *I am skeptical of most investments in these tools.*

Surprisingly to us, most of the comments that are dismissive of the use of IS in EM are not from those who are practitioners only (13 of the negative comments) but from those who have some research and/or academic experience or did not specify their role (34 negative comments). As exemplified in the comment, "What if your IT section goes down?", some respondents feared that use of IS would replace, rather than assist, emergency managers in their work or that education about IS requires removing from curricula traditional EM educational skills. This surprising result is a call for better informing the community of the role of technology in EM.

DISCUSSION AND CONCLUSIONS

A limitation of the results of this research is that not all respondents answered all questions. The demographic questions were at the end of the survey and 73 respondents did not answer all of them. Thus, we were unable to capture a complete picture of differences in perceptions of course utility by characteristics of the respondents. Also, the survey did not include any questions that would reveal the level of IS experience of the respondents. While membership in ISCRAM can be a rough indicator of whether the respondent had experience in IS, it is not a strong enough indicator as not all ISCRAM members have IS experience and not all respondents who may have IS experience are members of ISCRAM. Future research instruments should include the collection of this data. The sample sizes for groups of respondents from countries other than the U.S. were small. Additional data need to be collected from EM professionals outside of the U.S. to ascertain if curricula need to be markedly different for different geographic and political regions.

In reaching conclusions from the data analyses, the researchers reviewed all quantitative and qualitative analysis results and synthesized them into coherent observations and conclusions.

Some of the differences in course ratings between practitioners and academics/researchers may be because practitioners who have no research or academic experience are likely to be mostly focused on the disasters that occur in their location; respondents with academic and/or research experience likely take a more global view and think more about how some disasters can have far reaching effects (e.g. volcanic activity affecting air traffic). We also note that public health issues have not been generally recognized as a concern beyond the medical field. This is troublesome given the potential for major problems in the disaster e-health domain with, for example, electronic health records, telehealth, RFID, etc. Recent events (e.g. the Zika problem) and the increasing need to have access to online medical records are likely to broaden the understanding of the EM nature of health crises. Work is underway to define an e-Health roadmap for education and training in disaster management (Norris et al., 2015).

The analysis of the qualitative data has uncovered a schism in attitudes towards IS and the inclusion of EMIS content in EM programs. Some of the emergent expressions of resistance to IS in EM may have been a result of respondents not having had experience with well-designed collaborative IS that would improve outcomes of their activities. There were those who were hostile to technology, those who embraced it and understood the need for it in EM, and those who accepted it albeit with some trepidation. This suggests that emergency management is an evolving field and that programs must be flexible and sensitive to both the needs for the future and the attitudes and perceptions from the past. One respondent, in addressing the course on Sensors and Network Systems for EMIS, wrote, “Should help EM professionals ask intelligent questions of consultants and determine the validity of the claims made about products under consideration.” This comment is insightful because, even if an emergency manager will not be personally interacting with technology, the use of technology is here to stay and an effective manager will need to understand it. The resistance expressed by some respondents may have many root causes such as a fear of displacement of the human role and actual experience with currently developed IS that do not work well on the ground in real situations. This is our challenge: it is not sufficient to develop a curriculum to prepare the emergency managers of the future; we must also understand and be sensitive to the perceptions of current emergency managers, educate them to overcome misconceptions about the role of IS in EM that lead to resistance to the use of IS, and include outreach to systems designers in our efforts.

The spontaneous comments highlight the debate on the overall importance of information systems for emergency management and suggest that this is a topic that deserves further research. A next step in understanding would be to interview practitioners to drill down and further explicate the resistance to, and concerns about, IS in EM. Understanding the experiences practitioners have had, both positive and negative, with IS in their work is concomitantly critical. An additional survey with questions that allow for statistical analysis that can control for this misunderstanding, would also be helpful to tease out the true value to the profession of proposed courses.

Until this deeper understanding is reached, it is not prudent to propose a full curriculum. The General EM course ratings are unlikely to be affected by resistance to EMIS. Additionally, the highest rated EMIS courses had mean ratings high enough to suggest that they would need to be core to a master’s program (focused on IS or other focus). Therefore, the following preliminary, and incomplete, curriculum of required courses is proposed, leaving room for electives:

CORE GENERAL EM COURSES	**CORE EMIS COURSES**
Professional Characteristics and Organizational Practices for EM	Social Media for EMIS
Planning Foresight, and Risk Analysis and difficulties of the recovery effort	Decision Support Systems for Emergency Management
Case Studies of Failures in Emergency Management	Requirements for Emergency Management Information Systems (EMIS)
Disaster Types and Characteristics	Collaborative Problem Solving Using EMIS

Table 6. Preliminary Curriculum Recommendations

Overall, the qualitative and quantitative data gathered suggest that the proposed courses are appropriate but that flexibility be designed into curricula to meet the varied and changing needs in emergency management.

The emergent comments related to resistance to IS in EM are also a call to ISCRAM and other professional organizations, to engage in outreach to inform EM professionals of the usefulness, and inevitability, of using IS in EM. More importantly, communities such as ISCRAM fundamentally need to **listen** to EM professionals to be able to understand the reality of disaster situations and how IS can be designed to effectively serve emergency managers. The professionals, and students, need to be reassured that IS will not replace, but rather augment professional activities and decision-making. Outreach ideas include: white papers published in professional organizations' newsletters and web sites, workshops conducted at professional meetings, etc. For this to be effective, organizations need to collaborate and prepare joint activities. In essence, we need to work together on tangible problems in order to break down the barriers between the communities and form a joint approach to IS for emergency management. This is a call to ISCRAM to reach out to other organizations (e.g. IAEM, TIEMS) and lead this effort.

This resistance also suggests that when IS is developed for EM, the developers must include as part of the team, or as active stakeholders in the process, members from the EM community so that the systems meet the stakeholders' needs and the stakeholders can be comfortable with the system functionality.

The tasks before the ISCRAM Education Committee, and all in the EM community, are many. This research and the recommendations emerging from it are a good foundation for collaborative work that has the potential to make EM education, and therefore practice, more effective, more responsive, and better able to play an active role in determining the direction for moving into the technological age.

ACKNOWLEDGMENTS

We thank the members of the ISCRAM Board of Directors, ISCRAM Education Committee (particularly Victor Bañuls and Lili Yang, who contributed to earlier papers on this project), IAEM (the International Association of Emergency Managers) and survey respondents for their support and participation in this project.

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APPENDIX A: DESCRIPTIONS OF COURSES

General EM Courses	
Course Name	**Description**
Professional Characteristics and Organizational Practices for EM	Included topics will be the responsibility of Emergency Managers in various government agencies and nongovernmental organizations, the functions of the various EM agencies, business continuity, and the phases of emergency management from planning through recovery.
Disaster Types and Characteristics	With a focus on both natural and manmade disasters, this course will focus on the disasters most likely in the country or region where the course is taught. The content will include challenges and necessary responses for specific types of disasters. Disasters in other areas will also be more briefly addressed to inform those who move to new locations.
Planning, Foresight, and Risk Analysis	This course focuses on planning, risk analysis, and mitigation options to make responses more effective and to reduce the size and difficulties of the recovery effort. The course also addresses how to evaluate the effectiveness of the human and system performance. Included would be analyses of approaches to similar disasters in other locations. This course may need to be modified periodically based upon new findings and advances.
Public Health and Medical Services	Topics in this course will include the characteristics of medical facilities in various types of locations and their ability to respond to various types of disasters. Requirements for responding to different types of disasters (e.g. pandemics, release of poisonous materials) will be included in the course. Public Health courses addressing pandemics that may cross international boundaries will require an international treatment.
Fire Fighting Characteristics and Situations	Study of the range of fire types and what resources are needed to respond to them. What are the desirable mitigation factors which will reduce the likelihood of fires? How does one assess the needed resources and the desirable training for the fire fighters to handle an increasing range of possible emergencies? This course is for information and analysis purposes and is not intended to provide the physical training needed by firefighters.
Security and Terrorism Characteristics and Situations	Study of the involvement of Emergency managers in terrorist activity, especially that which has a wide impact (e.g. dirty bomb) or high casualties (e.g. explosion)
Emergencies in Developing Countries	A focus on understanding the difficulties that developing countries have in responding to a wide range of disaster types and how they can best manage to cope with such situations. Other topics include the operations of humanitarian organizations and the problems inherent in the movement of large numbers of refugees
Case Studies of Failures in Emergency Management	Learning from failures in EM has provided for significant improvements and changes in response and recovery practices. Reports and books on prior disasters will be discussed to provide useful insights and an understanding of prior experiences.
Critical Infrastructures and Their Interactions	Understand all of the critical infrastructures that service a populated area is critical for effective response and planning. Disasters often cause unexpected interactions between these infrastructures which makes response more difficult. In the United States the aging of the infrastructure is an additional critical problem which adds to the potential and complexity of failures and disasters.
Legal, Ethical, and Policy Concerns	Topics covered include the legal and ethical (e.g. privacy) issues Emergency Managers face in the development of procedures and policies and their implementations. The primary focus will be on the issues in the location served by the institution with some comparisons with concerns in other locations as well.

EMIS Focused Courses	
Course Name	**Description**
Requirements for Emergency Management Information Systems (EMIS)	A focus on the functions a computer system must be able to perform to assist humans in dealing with emergency situations most effectively and efficiently.
Decision Support Systems for Emergency Management	This course, requiring the proposed course on Requirements for Emergency Management Information Systems as a prerequisite, will focus on the support IS can provide for decision making in all phases of an emergency. It will address individual and group decision processes and how an IS can support them (e.g. the types of information needed, mitigating possible biases through feedback and analysis). All decision makers will be considered. Review of the literature and case studies will uncover ways IS can be improved to better support decision making.
Human Computer Interface (HCI) Design for EMIS	The properties of a computer and information interface that allow humans, as individuals and groups, to focus on complex situations and gather necessary information to determine timely solutions to difficult and rapidly changing events. The similarities and differences in HCI requirements for different systems (e.g. Command and Control, mobile devices deployed in the field) will also be discussed.
Sensor and Network Systems for EMIS	The use of sensors and other field devices to gather timely information about a given situation in order to respond quickly to crisis will be addressed. Both hardware sensors and computing devices used by responders, other professionals, and citizens will be discussed.
Social Media for EMIS	As a communication medium, Social Media is currently used, and has the potential for use, for dissemination and collection of information between government agencies, public entities, and a mixture of the two. Each paradigm has both challenges and opportunities in all phases of Emergency Management. Use by official organizations (e.g. government, NGOs) as well as the public and the benefits and risks of integrating the two will be addressed in the context of processes, procedures, policies, technical requirements, and attitudes.
Participatory Databases for EMIS	Databases that people can contribute to and can extract useful information from as well as engage in topical discussions are the topic of this course. Many of these databases will have public access and/or will be geographically oriented. Being able to set up and administer these databases and applications will be a requirement for many Emergency Managers. A basic understanding of the necessary roles and activities in database management is the goal of this course.
Collaborative Problem Solving Using EMIS	The focus of this course is to be able to evaluate systems and tools that provide for dynamic collaborative solving methods and process in emergency management. As any crisis, or potential crisis, is of mutual interest to different professionals, they need the support of tools that will allow a quick collaborative response to unexpected response problems.
Information Systems Evaluation	Overview and practice with qualitative and quantitative methods for involving users to obtain feedback on usability and usefulness of a system. Includes interviews, "thinking out loud" protocols, surveys and experiments.
Advanced Topics in IS for EM	A survey course to examine the newest trends in IS for Emergency Management. A basic understanding of such systems and tools as modeling and simulation, geographical information systems (GIS), and analytic tools will be discussed. Each semester another topic or type of system can be the focus of the semester. Institutions may choose topics that are especially germaine to their constituency and location.
A Master’s Thesis	(Programs with focus on EMIS only) A one or two semester course with representation on the committee from a computing sciences department if possible. Departments are encouraged to hold regular seminars for all master's students at which practitioners will be invited to speak about their real world experience. The regularity and ability of a department to do this will depend upon many factors such as the size of the department.
Digitizing a Paper World	(General EM Master program only) This elective would provide guidance for moving from paper based to electronic based records. Included would be descriptions of different types of systems and applications, processes for transitioning, and training techniques. This course would be more basic than the Requirements for Emergency Management EMIS course and would have more of a practitioner and process focus.

Collaboration among Humanitarian Relief Organizations and Volunteer Technical Communities: Identifying Research Opportunities and Challenges through a Systematic Literature Review

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ABSTRACT

Collaboration is the foundation to strengthen disaster preparedness and for effective emergency response actions at all levels. Some studies have highlighted that remote volunteers, i.e., volunteers supported by Web 2.0 technologies, possess the potential to strengthen humanitarian relief organizations by offering information regarding disaster-affected people and infrastructure. Although studies have explored various aspects of this topic, none of those provided an overview of the state-of-the-art of researches on the collaboration among humanitarian organizations and communities of remote volunteers. With the aim of overcoming this gap, a systematic literature review was conducted on the existing research works. Therefore, the main contribution of this work lies in examining the state of research in this field and in identifying potential research gaps. The results show that most of the research works addresses the general domain of disaster management, whereas only few of them address the domain of humanitarian logistics.

Keywords

Volunteer Technical Communities, Response Agencies, Disaster Management, Decision-Making, Humanitarian Logistics.

INTRODUCTION

Large scale disasters such as 2010 Haiti Earthquake or 2013 Philippines Typhoon caused high losses in terms of human lives and property damage in recent years (Harvard Humanitarian Initiative, 2011; Vieweg et al., 2014). In the aftermath of such disasters, timely information is needed in order to contribute to situational awareness. Especially for logistics operations information on the condition of required infrastructure and resources such as roads or airports is critical (Horita et al., 2014).

In the last years, the spread of information and communication technology (ICT) has enabled affected people to directly contribute to situational awareness; for example, by reporting blocked roads or destroyed airports (IFRC, 2013). However, humanitarian organizations often do not have the resources to handle this emerging flow of information (Harvard Humanitarian Initiative, 2011). Therefore, volunteer groups stepped into the evolving information space by monitoring and filtering the new information flow in the aftermath of disasters (Capelo et al., 2012). In this regard, the 2010 Haiti Earthquake was important for the raising of several volunteer technical communities (VTCs) (Starbird & Palen, 2011). By offering information on affected people and infrastructure, VTCs provide timely and valuable information products for relief operations.

Although VTCs are important actors in nowadays humanitarian response and offer a high potential to support relief operations, “the challenge lies in enabling humanitarian organizations and V&TCs to better understand each other and to develop opportunities for collaboration that harness the full potential of the resulting partnership” (Capelo et al., 2012). Issues of trust, reliability or integration of data are exemplary obstacles to collaboration between these volunteer groups and the traditional actors in humanitarian response (Harvard Humanitarian Initiative, 2011).

Several research works have provided specific insights of collaboration problems and suggested possible ways forward. Within these works, Haworth (2016) identifies and addresses obstacles such as missing trust of emergency managers in volunteer information or perceived legal concerns. Gralla et al. (2015) give an overview of the decisions to be made after disasters by emergency managers through a framework for such decisions and information requirements. However, to best of our knowledge, no literature reviews have been carried out to summarize the collaboration between VTCs and formal humanitarian organizations.

Therefore, the main goal of this work is to provide an overview of the existing literature by conducting a SLR on the collaboration among formal organizations and VTCs. An SLR “involves both the identification of high quality papers and the evaluation of their applicability to the study” (Vom Brocke et al., 2009). Thus, this study examines the following research question:

RQ. How can formal humanitarian organizations and VTCs collaborate to support decision-making with crowdsourced geographic information?

The remainder of this work is structured as follows: Section 2 presents the basic concepts used in the paper. Section 3 describes the research methodology regarding the SLR. Section 4 contains an analysis and discussion of the state-of-the-art of the collaboration among humanitarian organizations and VTCs. Eventually, Section 5 concludes with a summary and future works.

BACKGROUND

A disaster is defined by UNISDR (2007) as “a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources”. Disaster management aims at lessening the impact of such disasters by use of plans and arrangements to coordinate and guide involved humanitarian organizations in their response to emergency needs (IFRC, 2016; UNISDR, 2007). Within disaster management, humanitarian logistics represents the sub domain of “planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people” (CSCMP, 2016; Thomas & Kopczak, 2005). Thomas & Kopczak (2005) identify humanitarian logistics as an essential sub domain of disaster management due to its relevance for effectiveness and speed of overall relief operations.

Accurate and up-to-date information is essential for supporting the tasks of disaster management, especially in humanitarian logistics, owing to its characteristics. Crowdsourced Geographic Information (CGI) – user-generated information that is crowdsourced and relies on collaborative web platforms, specific web applications and/or mobile phone apps (Goodchild, 2007) – has emerged as an important source of information for disaster management (Albuquerque et al., 2017). However, humanitarian organizations often do not have the resources to handle this emerging flow of information (Harvard Humanitarian Initiative, 2011). Therefore, Volunteer Technical Communities (VTCs) emerge as an important mechanism to support humanitarian organizations. VTCs can be defined as volunteer-based, virtual communities that "apply and leverage their technical skills in collecting, processing and managing data in support of response efforts for disasters" (Liu, 2014). Thereby, they provide information-related services such as aggregated and mapped social media streams to actors involved in disaster management. VTCs consist of members of different backgrounds, most of them keen on innovative technologies (Capelo et al., 2012). Main differentiating factors of VTCs from formal humanitarian organizations are their open-source ideology, their flexible structure, the altruistic nature of their motivation as well as their enthusiasm for partnership (Capelo et al., 2012).

This paper deals with the collaboration of the aforementioned types of actors: response agencies and VTCs. Collaboration shall be defined as a "mutually beneficial and well-defined relationship entered into by two or more organizations to achieve common goals. The relationship includes a commitment to: a definition of mutual relationships and goals; a jointly developed structure and shared responsibility; mutual authority and accountability for success; and sharing of resources and rewards" (Mattessich & Monsey, 1992). Collaboration is a fundamental component of any emergency response (Waugh & Streib, 2006). However, it is a complex topic because it requires analysis from different perspectives for the efficient design and development of tools and technologies to support collaborative work.

RESEARCH METHODOLOGY

For addressing the research question on the collaboration among VTCs and formal humanitarian organizations a Systematic Literature Review (SLR) has been conducted. Vom Brocke et al. (2009) introduce an SLR as a means of rigorously conducting literature reviews and searches in the Information Systems (IS) domain. It helps to reveal potentially open research gaps (Vom Brocke et al., 2009). In order to do so, they presented an iterative review process consisting of the following phases: (i) the definition of review scope, (ii) the conceptualization of topic, (iii) the literature search, (iv) the literature analysis and synthesis, and (v) the formulation of a research agenda.

For the first phase, the taxonomy of Cooper (1988) gives guidance on how to scope the review. The literature review underlying this paper is aimed at specialized scholars and based on research outcomes and applications. Goal of the review is to identify central issues of the topic and to evaluate the state of literature based on potential research gaps. The next phase, *conceptualization of topic*, has already been addressed through the definitions in Section "Background".

The objective of the *literature search* is to capture the largest possible number of paper, and remove those which do not meet the criteria defined (Okoli, 2015). It consists of certain sub phases: *journal search*, *database search*, *keyword search*, *in-/exclusion criteria* and *back- / forward search* (Vom Brocke et al., 2009). Journals from the domains of IS and the domain of disaster management serve as indicators for the selection of appropriate databases. Thus, the three databases Scopus, ACM Digital Library and Web of Science have been chosen for conducting the review.

Table 1. Search string structure

(("disaster management" OR "emergency management" OR "crisis management" OR "disaster response" OR "emergency response" OR "crisis response" OR "response agenc*"[1)] OR "relief organization") OR ("humanitarian logistics" OR "disaster logistics" OR "emergency logistics" OR "crisis logistics" OR ("humanitarian aid" AND "logistics") OR (("disaster relief" OR "emergency") AND ("logistics" OR "supply chain*"[1)])))) AND ("volunteer techn* communit*"[1)] OR "VTC" OR "volunteer* geographic information"[1)] OR "VGI" OR "crowdsourc*"[1)] OR "crowdtask*"[1)] OR "microblogging" OR "digital humanitarian*"[1)])

[1)] The asterisk-symbol allows for minor variations such as singular and plural forms

For the *keyword search* the search string has been derived from the conceptualization of the topic and the research question (Table 1). The following inclusion criterion (IC) was defined to ensure that only papers contributing to the research questions are selected:

IC-1: The paper integrates the topics of disaster management / humanitarian logistics and of VTCs, it is especially concerned with collaboration of VTCs and response agencies.

Accordingly, a set of exclusion criteria (EC) was specified:

EC-1: The paper is not electronically available on the web through institutional subscriptions that the authors currently have.

EC-2: The paper is not presented entirely in English.

EC-3: The data entry does not refer to a peer-reviewed scientific paper.

After primary study selection based on these criteria a back- and forward search has been conducted based on all primary studies' citations. The overall process of the literature search, which was conducted in May 2016, is visualized in Figure 1. During the literature search a high number of papers did not meet IC-1 since they do not deal with the behavioral aspect of collaboration among response agencies and VTCs, but are more concerned with technical aspects such as crowdsourcing platforms.

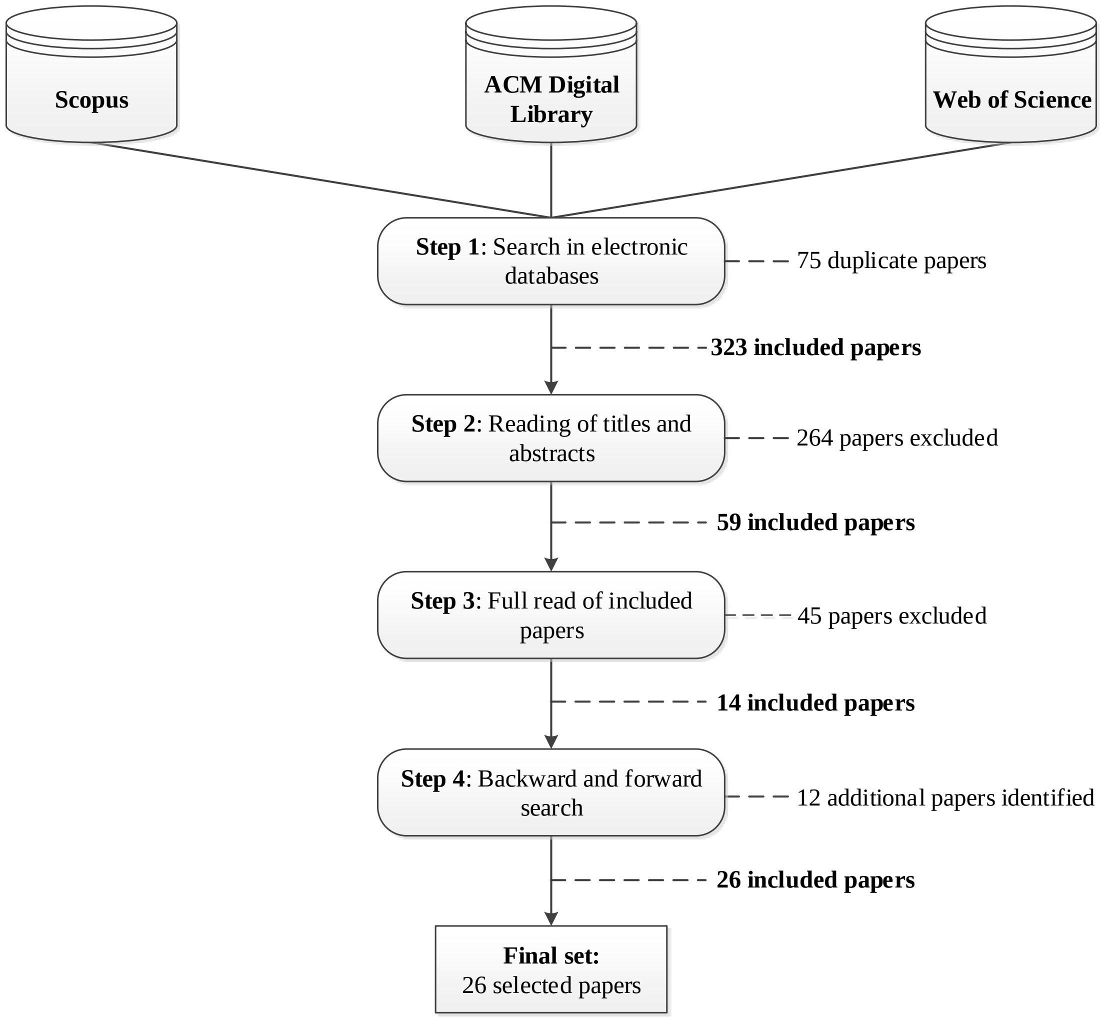

Figure 1. Literature Search Process

As a result of the literature search, 26 papers were selected as a basis for the analysis and discussion (Table 2).

Table 2. List of selected papers

Year	Conference (ID/Ref.)		Journal (ID/Ref.)		Workshop (ID/Ref.)	
2016	C01	Hellmann et al. (2016)	J01	Haworth (2016)		
	C02	Horita et al. (2016)				
2015	C03	Gralla et al. (2015)	J02	Becker & Bendett (2015)		
	C04	Kaminska (2015)	J03	Hughes & Tapia (2015)		
	C05	Link et al. (2015)				
	C06	van den Homberg & Neef (2014)				
2014	C07	Cobb et al. (2014)	J04	Liu (2014)		
	C08	Horita et al. (2014)	J05	Tapia & Moore (2014)		
	C09	Meesters & van de Walle (2014)				
	C10	Soden & Palen (2014)				
	C11	van Gorp (2014)				
	C12	Vidolov (2014)				
	C13	Vieweg et al. (2014)				
2013	C14	Starbird & Palen (2013)	J06	Kerle & Hoffman (2013)		
2012	C15	St. Denis et al. (2012)				
2011	C16	Chamales & Baker (2011)	J07	Barrington et al. (2011)	W01	Ortmann et al. (2011)
	C17	Gao et al. (2011)	J08	Ghosh et al. (2011)		

After conducting the literature search, information was extracted from the papers in a concept-oriented way (Webster & Watson, 2002) based on four extraction dimensions. The first extraction dimension identifies the domain addressed in the selected papers, either disaster management or its sub domain of humanitarian logistics acknowledging its high criticality for any relief operation (Blecken, 2009). The following extraction dimensions examine the focal point of collaboration between humanitarian organizations and VTCs to answer the research question. The initiation direction of the information flow between the two actors, following Meesters & van de Walle (2014), is contained in the second dimension. Information on different types of disaster management interfaces, following Liu (2014), is extracted using the third extraction dimension. The fourth extraction dimension identifies different types of collaboration practices used by response agencies and VTCs (Vidolov, 2014).

RESULTS AND DISCUSSION

This section contains the analysis and discussion of the 26 selected papers. Figure 2 shows the distribution of these papers classified by year and their publication venue. The distribution of publication years of the papers is limited to the range from 2011 up to now with a peak in 2014. This rise in literature after 2010 seems reasonable due to the rise of VTCs' engagement during 2010 Haiti Earthquake (Zook et al., 2010).

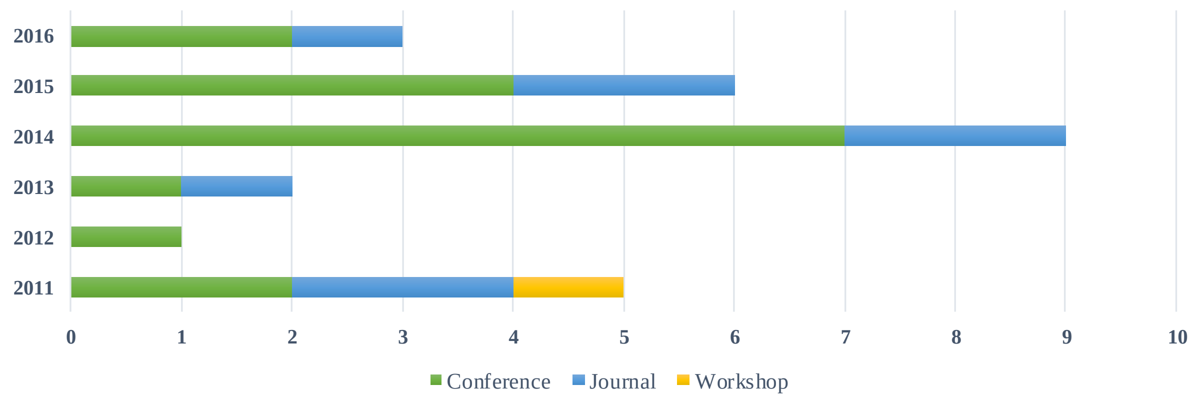

Figure 2. Paper Distribution by Year and Publication Type

Addressed Domain

Most of the selected papers (23 of 26 papers) are concerned with the general domain of disaster management (Table 3). Gao et al. (2011) developed a platform that facilitates coordination of emergency requests and response efforts of humanitarian organizations. Another example of studies on collaboration in disaster management is Vieweg et al. (2014). The authors use interviews with the Office for the Coordination of Humanitarian Affairs' (OCHA) staff to assess the potential contribution of classified twitter data which has been classified by VTCs such as MicroMappers.

Three of the 26 selected papers specifically address the sub domain of humanitarian logistics (Table 3). Horita et al. (2016) present the observation-aware Decision Model and Notation (oDMN) which connects tasks, decisions, information and data sources of actors in emergency management. They apply their notation specifically to a logistics context in the aftermath of 2015 Nepal earthquake and thus pay attention to specifics of this domain such as infrastructure conditions or resource constraints, whereas Vieweg et al. (2014) use a case study of Typhoon Yolanda without focusing on a specific domain.

Table 3. Classification of addressed domain

Attribute	Paper
Disaster Management	C01, C03, C04, C06, C07, C09, C10, C11, C12, C13, C14, C15, C16, C17 J01, J02, J03, J04, J05, J06, J07, J08 W01
Humanitarian Logistics	C02, C05, C08

Within the 26 selected papers the sub domain of humanitarian logistics is rather poorly covered concerning the collaboration among formal humanitarian organizations and VTCs. However, some special characteristics of humanitarian logistics raise the need for such research: The logistics function is distinguished from general relief operations by its strong dependency on physical infrastructure (Blecken, 2009). The existence and condition of roads, airports or the availability of fuel can mean the difference between successful and failed operations (Kovács & Spens, 2007). Especially for providing such infrastructure-related information, VTCs could be used as valuable collaboration partners (Blecken, 2009).

Another distinction criterion is the privatization of logistics operations (Van Wassenhove, 2006). An "outsourcing of logistics services to third parties" (Blecken, 2009) is apparent within humanitarian logistics. One implication of this is that additional to response agencies also private companies have to be coordinated within humanitarian logistics (Cozzolino, 2012). Thus, it is necessary for future research to examine for example the influence of privatization on collaboration in the disaster management environment.

Information Flow Initiation Direction

Many of the provided information products of VTCs are generated without specific request of response agencies, thus the information flow between response agencies and VTCs is initiated bottom-up (Table 4). There are rather generic information products such as maps which show where help is needed by supplying textual or visual information (van Gorp, 2014). These provide basic information which addresses the information needs of several response actors. In contrast, there are also more specialized products generated by VTCs such as Event Diaries in which specific information such as location and capacities of nearby hospitals is synthesized during disasters. For using such specialized products, response agencies have to be educated by the providing communities (Starbird & Palen, 2013).

Several papers also introduce examples and concepts of top-down initiations of the information flow (Table 4). For example, networks of volunteers such as GEO-CAN for building damage assessment are based on specific information needs of response agencies. If the volunteers are not aware of these information needs "it remains unclear precisely what information is required by individual responders and decision-makers" (Gralla et al., 2015). However, top-down initiations require a lot of clarification of information requirements short after or even prior to a disaster.

Table 4. Classification of information flow initiation direction

Attribute	Paper
Bottom-Up Initiation	C09, C10, C11, C14, C16, C17
	J01, J05
	W01
Top-Down Initiation	C03, C04, C05, C07, C08, C09, C13, C15
	J06, J07, J08
Bidirectional Initiation	C01, C02, C06
	J02, J03
Not Addressed	C12
	J04

A bidirectional connection of the decision-making process of humanitarian organizations and the data collection of VTCs is more rarely found in the 26 selected papers (Table 4). One way to handle a bidirectional information flow between the actors is the use of information brokers or mediators. These brokers "function as boundary spanners, demonstrating insight into each individual domain of the collaborative effort" (Hellmann et al., 2016). Hellmann et al. (2016) report on a rather traditional form of brokering activities in which individuals act as information brokers by providing contact lists or data inventories. In contrast, Hughes and Tapia (2015) point out that also whole networks such as the Digital Humanitarian Network (DHN) can serve as such intermediaries and that they tend to employ new, innovative processes as part of the brokering activity.

To date mainly large organizations such as the United Nations OCHA or the World Bank collaborate with VTCs (van Gorp, 2014). The analysis of the information flow initiation direction provides one possible reason for this fact: Top-down initiations such as the use of closely tied networks of volunteers are no good option for small response agencies due to their lack of resources for coordination (van Gorp, 2014). Furthermore, information products which are generated bottom-up by VTCs will often not meet the information requirements in case of specialized small agencies. Therefore, bidirectional mechanisms are required for small agencies to assess the value of provided information products against the background of their specific information needs. Hughes & Tapia (2015) suggest an "a-la-carte system where digital volunteers can advertise services and emergency responders can then order the services they need". As indicated by the selected papers of the review there is only a small number concepts for bidirectional information flow initiations available in literature. This poses the need for further concepts for matching information requirements and volunteered information, thus enhancing the use of such information as decision-support for emergency managers (Albuquerque et al., 2017).

Interface Type

Concerning social interfaces, ten of the 26 selected papers elaborate on concepts such as trust or organizational culture (Table 5). Through interviews Haworth (2016) recognizes for example that the traditional, procedure-driven top-down power structure of emergency management is disrupted by the spontaneous, unstructured nature of VTCs' information products. Similarly, Hughes & Tapia (2015) state that the "key difference between professional response organizations and digital volunteer groups is their approach to information as either closed or open". Whereas VTCs use open and transparent processes and standards to handle information, traditional agencies clearly define ownership and intellectual property rights of information.

Seven papers discuss the interfaces between VTCs and response agencies from a technological perspective (Table 5). The main challenge from this perspective is the integration of VTCs' systems into the highly proprietary systems used by response agencies for day-to-day operations (Tapia & Moore, 2014). One way to address this challenge is Linked Open Data presented by Ortmann et al. (2011) which offers a common exchange format. In their approach information provided by VTCs is transferred into RDF-triples by volunteers who can then be integrated into response agencies' systems.

Table 5. Classification of interface type

Attribute	Paper
Social Interface Type	C09, C10, C11, C12, C14, C15, C16 J01, J03, J05
Technological Interface Type	C01, C06, C08, C13, C17 J05 W01
Organizational Interface Type	C01, C02, C04, C05, C07, C13, C15 J02, J03, J07, J08
Political Interface Type	C16 J01
Not Addressed	C03 J04, J06

Organizational interfaces are also often discussed in the selected papers (Table 5). The concept of information brokers among VTCs and response agencies is part of this organizational perspective: These brokers often use contact lists and data inventories "in order to promote connecting the right people to achieve a given goal" (Hellmann et al., 2016). Examples for such brokers can also be networks such as GEO-CAN which are used to reach a high number of experienced volunteers (Barrington et al., 2011; Ghosh et al., 2011). One possibility for researching organizational interfaces issues could be the conducting in-depth cases studies with the aim of advancing understanding on the role of brokers among VTCs in collaborative mapping activities and response agencies (e.g. the Humanitarian OpenStreetMap Team and the Missing Maps Project).

Political interfaces between VTCs and humanitarian organizations are the only type of interfaces which are sparsely represented in the selected papers (2 of 26 papers) (Table 5). Haworth (2016) recognizes the threat of accountability and legal complications due to decisions based on to some extent unreliable information provided by VTCs. Improved legal protections are required for allowing agencies to base their decision on such information . Chamales & Baker (2011) elaborate on necessary protection of individuals' identity against malicious groups in addition to legal protection of response agencies.

Perceived legal concerns of response agencies for example of being considered responsible for unverified information by VTCs can pose hindrance to collaboration with such volunteer groups (Haworth, 2016). Therefore, on the one hand governments are challenged to improve legal protection for response agencies which are basing their decisions on information provided by VTCs (Haworth, 2016), on the other hand researchers are challenged to further research the impact of faulty information and issues of accountability on VTCs' and response agencies' collaboration. Quality assessment is an important step in all CGI sources since the information comes from unknown sources and with unknown quality (Albuquerque et al., 2017). Thus, works that propose a framework of the methods used to assess the quality of CGI in absence of authoritative data are really required.

Collaboration Practice

Collaboration practices can be classified into reconfiguring and fusing ones. Reconfiguring practices refer to transformational processes at either response agencies or VTCs in order to prepare for new collaboration relationships (Vidolov, 2014). Fusing practices are defined as the construction of a collaboration network between a response agency and a VTC including defined roles and responsibilities (Vidolov, 2014). Of the 26 selected papers, 19 elaborate on fusing practices and six on reconfiguring practices (Table 6).

Table 6. Classification of collaboration practice

Attribute	Paper
Reconfiguring Practice	C03, C09, C10, C11, C12 J01
Fusing Practice	C01, C02, C04, C05, C06, C07, C08, C11, C12, C14, C15 J02, J03, J04, J05, J06, J07, J08 W01
Not Addressed	C13, C16, C17

Concerning reconfiguring practices, five papers deal with reconfiguring the VTCs' side. Soden & Palen (2014) for example take the Humanitarian OpenStreetMap Team (HOT) as an example of how a volunteer community that emerged out of disaster response formalized in the following years. Vidolov (2014) states that by formalization of VTCs these groups can overcome potential problems of reliability and trust perceived by formal response agencies. In contrast to Soden & Palen (2014) who focus on examining VTCs, Vidolov (2014) underlines the necessary reconfiguration of both collaboration actors: They state that in order to prepare for using voluntarily contributed information, formal humanitarian organizations need to become more open and flexible in comparison to their current bureaucracy. For example OCHA has recently introduced structural changes concerning de-centralization, flattening of hierarchies and openness (Vidolov, 2014)

The fusing collaboration practices can be classified according to Majchrzak et al. (2012): Centralized, traversing fusing practices include making knowledge bases of and dependencies between the actors explicit in advance to disasters (Harvard Humanitarian Initiative, 2011). The local, transcending approach "concerns the emergence of local collaborations between various traditional and non-traditional actors that are developing a collaborative ordering through 'learning-by-doing'" (Vidolov, 2014).

14 of the 19 fusing practices mentioned in selected papers are on central, traversing fusing practices. For example the TIDES program of the US Department of Defense is a central fusing practice. Such networks which are not related to a specific disaster make knowledge bases of the involved groups explicit by interagency field experiments in between disasters (Becker & Bendett, 2015). Such training and education efforts in between disasters are also proposed by Starbird & Palen (2013) and van Gorp (2014). Another part of the literature on fusing practices is of local, transcending nature (6 papers). Networks such as GEO-CAN that have been established in direct response to a specific event include ad-hoc collaboration efforts (Barrington et al., 2011; Ghosh et al., 2011). Tapia & Moore (2014) state that such initial, ad-hoc collaborations, which have often been conducted in the past years, can create trust in the long term.

Local fusing practices represent ad-hoc collaboration efforts in a specific disaster context and thus represent collaboration of actors who have not worked with each other before. These local collaboration practices can actually be seen as the basis for central fusing approaches since in practice collaboration often emerges out of initial courses of interaction (Vidolov, 2014). Accordingly, starting directly with central fusing practices is no easy task for emergency environment actors if they did not experience this initial courses of interaction. Both types of fusing practices are apparent in literature but the question remaining unsolved is how to use local fusing practices as concrete basis for collaboration agreements and central fusing practices. Thus, future research should examine concepts of community-centeredness in disaster management in order to prepare for enhanced long-term collaboration of VTCs and response agencies.

CONCLUSION

This paper has presented the results of an SLR on the collaboration of formal humanitarian organizations and VTCs. Concerning the initial research question, different approaches for collaboration have been identified in the 26 selected papers of the literature search, using four extraction dimensions. The biggest benefit of this work thus lies in examining the state of research in this field and in identifying potential research gaps indicated by the selected papers.

Through this SLR, it has been realized that most of the selected papers address the general domain of disaster management, whereas only few of them address the specific domain of humanitarian logistics. Future work needs to research for example the influence of privatization on collaboration as this is one special characteristic of humanitarian logistics. Furthermore, concepts are required for quality assessment of possibly faulty volunteered information in order to protect response agencies against legal consequences. Especially small organizations need to be assisted in integrating such information by researching concepts for matching their information requirements and the provided volunteered information. In addition, the field of community-centeredness in disaster management is an important one in order to enhance long-term collaborations of volunteers and formal actors.

Thus, future work should be done to address the research gaps, which have been pointed out in Section 4. Moreover, future research in that direction will allow humanitarian organizations and VTCs to better understand each other and to develop opportunities for collaboration, allowing to seize the opportunities offered by resulting partnerships. One limitation of this work can be seen in the selected set of extraction dimensions since additional extraction dimensions can potentially identify further gaps during future work. Furthermore, within this SLR exclusively scientific studies regarding the collaboration of humanitarian organizations and VTCs have been reviewed. In future works, interviews with practitioners will be carried out aiming at identifying promising areas of future research.

ACKNOWLEDGMENTS

The authors would like to thank Daniel Link, who helped to devise the notion of this work and to formulate the initial research agenda. R.S.R. acknowledges financial support from the FP7 Marie Curie Actions/Initial Training Networks (Grant No. 317382). J.P.A. acknowledges financial support from CAPES (Grant No. 88887.091744/2014-01) and Heidelberg University (Excellence Initiative II/Action 7).

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Studying Virtual Teams during Organizational Crisis from a Sociomaterial Perspective

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ABSTRACT

In this paper, we propose sociomaterialism as a theoretical lens for studying virtual team management during organizational crisis. In applying this lens, we propose the use of pattern theory as the method of choice for documenting effective practices for managing virtual teams in organizational crisis settings.

Keywords

Virtual team, sociomaterialism, organizational crisis, shared mental models, adaptive use of IT.

INTRODUCTION

An ability to prepare for and manage organizational crises is becoming increasingly important in our world today. Due to the emergence of advanced information technology (IT) and the inherent nature of crisis settings, virtual teams (VTs) play a crucial role in managing many types of organizational crisis. Though significant knowledge has been accumulated about VTs in the past two decades, our knowledge of how VTs are effectively used in dealing with crisis events is lacking in terms of generalizable findings (Stachowski, Kaplan, & Waller, 2009).

Prior studies suggest virtual teams rely on team mental models (TMM), i.e. shared understanding of the team members on the task, the teams, and the technology, as an important mechanism through which VT performs tasks (Mathieu, Heffner, Goodwin, Salas, & Cannonbowers, 2000). In particular, IT as an integral part of VT, is used as a means to share information, communicate, and coordinate tasks; however, the consequences of adapting IT are often "associated with a range of organizational outcomes, many of which are emergent and unanticipated" (Orlikowski & Scott, 2009, p.436). In the case of VTs in crisis settings, with ambiguity of cause and effects and negative feelings, such as fear and anxiety by the VT members, the challenge rests in developing an understanding of the interaction between VT members' TMM and the IT capabilities they adaptively use in the time of crisis.

The notion of "sociomateriality" originally proposed by Orlikowski and Scott (2009) is a useful lens for examining VT's effectiveness in crisis with developing understanding on the complicated interplay of IT use and VT's TMM development. This perspective, in fact, is suggest to be the "promising stream of research" and the recommended approach to be taken by researchers in IS and organizations, especially in this increasingly digital world, to unfold the "black box" of IT adaptive use in organizations. By taking the sociomaterial view, it means a shift of focus from the impacts of IT on human to the boundless connections between IT and human activities and relations. The human-technology relationship within organizations can be understood better by recognizing the importance of both the material and social aspects. Further, sociomaterialists search for recurrent patterns in organizations relating to the entanglement of IT within organizations and believe that identifying such patterns can be useful knowledge about comprehending the organizations' functioning.

Thus, the primary goal of this paper is to introduce the notion of sociomateriality and examine its applicability on virtual team research, especially within the context of organizational crisis. Specifically, we propose to adopt a sociomaterial perspective to understand the interplay between the human's team mental model (TMM) and the non-human IT capabilities adaptation (AUIT) during crisis. Understanding this requires examining the entirety of the interactional context – human and non-human, virtual and face to face. A secondary goal of this paper is to identify an appropriate approach, i.e. a research method, for capturing the potential patterns of the sociomaterial assemblages of IT in virtual teams during crisis. Our paper contributes to both the virtual team and the crisis literature in providing a new perspective for studying crisis phenomenon and introducing a novel approach ("the pattern theory method") for capturing the interplay between technology and non-technology processes for virtual teams in crisis settings.

In the remaining sections of the paper, we first discuss some of the fundamental concepts. Then we present a discussion about the connection between organizational crisis research and sociomateriality. Next, we further examine how the sociomaterial view can be applicable to studying virtual teams in organizational crisis by presenting three implications of sociomateriality. In the last section, we present a promising method for describing the patterns to describe sociomaterial assemblages in organizational crisis. We conclude the paper with some implications of the proposed approach..

BACKGROUND

Organization Crisis and Virtual Teams

The multidisciplinary nature of the crisis domain has resulted in the participation of researchers from organizational behavior, organizational psychology, social cognition and information systems to examine various aspects of crisis. These topics range from the nature of crisis, crisis' origin, factors contributing to more effective crisis management, and impacts of crisis on organizations. Particularly, studies have found that the following factors can affect crisis management: crisis communication (both verbal and nonverbal), leadership style, manager's expectation, teams' shared understanding, members' interoperability, sense-making, situational awareness of organization members (Berggren, Johansson, & Ekström, 2016; Robinson, Maddock, & Starbird, 2015; Saoutal, Matta, & Cahier, 2015; Weick, 1988). In addition, recent studies suggest that power, politics and stakeholders' role in crisis management is also important (Doern, 2014).

Virtual team plays a vital role for organizations in crisis. Organizations can gain multiple benefits by using virtual teams in crisis, from low traveling costs to leveraging talent from around the world. For example, a few studies on online communities or social networks and crisis management has confirmed the significant positive role of virtual collaborations in managing crisis events (Jin, Liu, & Austin, 2014). At the same time, previous studies have also shown that organizations can experience greater amount of communication needs than usual and such communication can be intraorganizational, interorganizational, from organizations to the public, from the public to organizations, and within systems of organizations (Coombs, 2007; Dwyer & Hardy, 2016). In addition to the increased needs for communication, other common problems of crisis such as loss of control, new work assignment, perceived fear among organization members and lack of consensus also pose great challenges for virtual teams to maintain effectiveness during crisis (Jenkins & Goodman, 2015; Jung & Park, 2016; Pearson & Clair, 1998).

Previous studies on virtual teams have found that leadership, trust, and the emergent processes in virtual teams can be different from the traditional teams. For example, virtual teams tend to build "swift trust" in the team because of the short duration of the team and then this initially built "swift trust" may be reinforced or weakened because of the affective or capability based perceptions emerged later on (Jarvenpaa & Leidner, 1998). Further, leaders in virtual teams may exhibit less control and act more like a facilitator than in traditional face-to-face teams. Studies have also found that virtual teams rely on information technology (IT) capabilities for development of team mental models (similar concepts include shared mental models, shared understanding) (Mathieu et al., 2000).

While the findings summarized above are valid for virtual teams, we cannot easily generalize them for virtual teams in crisis situations. The key features associated with crisis, i.e. ambiguity, low probability and threat, make it distinct from other contexts in which VTs have been previously studied. In crisis, VTs may suffer from extreme stress, which may lead to a reduction in both individual and team level cognition and therefore changes in the emergent processes along with other aspects of virtual teams. A few studies have examined virtual teams in crisis situations. One such study found that teams that adopted a more flexible interaction pattern instead of a regular and predefined pattern show greater adaptability during crisis situation (Stachowski et al., 2009). Another study by Jenster and Steiler (2011) suggests that leaders in virtual teams during crisis should be more active instead of sitting silent so that members of the team have higher motivation throughout the "difficult time". Cheshin et al. (2009) suggest that virtual team members may face difficulties in correctly interpreting the emotions of their teammates through emails and other low-media richness communication tools. Further, such misunderstanding of peers' emotions can lead to inaccurate sensemaking and result in inaccurate team mental models development.

In summary, stress, high ambiguity, low probability, are critical issues associated with crisis that can affect one's emotion, cognition, and capability of using IT according to one's intention.

A Brief Summary of Socialmaterialism

The notion of "sociomateriality" was originally proposed by Orlikowski and Scott (2009). In their literature review on IT research in organizations, Orlikowski and Scott (2009) assert that there is an "inherent inseparability between the technical and the social" (Orlikowski & Scott, 2009, p.454) based on the notable unanticipated consequences of many "simple" technologies in organizations. They call for researcher's attention to move beyond examining technology, work, and organizations independently and focusing on the "emergent constitutive entanglement" (Orlikowski & Scott, 2009, p.457) among these three concepts. In other words, the sociomaterial view argues that human actors and technological objects emerge in the form of sociomaterial assemblages, which presumes that there are no independently existing entities with inherent characteristics. Sociomateriality draws on three intellectual approaches, i.e. sociotechnical systems, actor-network theory and practice theory (Cecezkecmanovic, Galliers, Henfridsson, Newell, & Vidgen, 2014).

Since the notion of sociomateriality was proposed, there has been debate over its relational ontology. In particular, the question of whether the technology and human entities only exist in relation to each other or exist physically no matter the interaction is highly contested (Jones, 2014). Considering the purpose of this paper, we do not delve deeper into this debates, and constrain our discussion of sociomateriality to its original form as proposed by Orlikowski and Scott (2009) with an emphasis on the examination of the entanglements of technology and human.

Moreover, in a response to the call made by Jones to be serious in employing the sociomateriality instead of using sociomateriality as a "flag", we summarize key concepts related to the sociomaterial perspective in Table 1. We also include Jones' empirical study in critical care as an example to show how notions of socialmateriality can be addressed in IS research.

Table 1. Summary of Key Concepts in Sociomaterial Perspective (Adapted from Orlikowski & Scott, 2009)

Concepts	**Definition**	**Examples** (Jones, 2014)
Socialmaterial Assemblages	Examining how materiality is intrinsic to everyday activities and relations.	Introducing computer-based clinical information system (CIS) in critical care unit (CCU) is not just a change in materiality, but a change in an array of social and material relations. It opens new possibilities, but the realization of these is not a fixed outcome of either the technology or social relations.
Relationality	The social and the material are inherently inseparable.	The reality of the CCU are all products of particular, contingent sociomaterial intra-actions, albeit in many cases these take place outside the immediate context of the CCU itself.
Performativity and practice	Enactment and the recurrent patterns identified in the sociomaterial assemblages	The computer models which shows the computer-aid diagnosis of patients' situation. The recurrent emotional process occur within the CCU.

Adaptive Use of IT, Team Mental Model, and the Interplay of These Two Concepts

Adaptive use of IT (AUIT)

In this paper, IT is not viewed as an independent variable for crisis outcomes, nor considered as a moderating variable that variously influences relationships between organizational variables and crisis outcomes. We theorize IT as constitutive of team members either individually and collectively adaptive use of IT capabilities. To this end, we use the term adaptive use of IT (AUIT) based on our previous work. By AUIT, we "recognizes both the users' interactions through and with IT tools in accomplishing tasks and the inherent functional capabilities of the IT artifacts." AUIT in virtual teams can be defined as the process by which "a virtual team modifies the way it uses one or more communication and collaboration technology capabilities."

In crisis situation, VTs may need to use centralized or integrated information systems, which not all team members fully understand the IT various capabilities, to support their actions. Further, CMTs may experience information overload and need to adapt to new communication and coordination schemes via information technology capabilities (McNeill, Gkaniatsou, & Bundy, 2014). In some other circumstances, VTs may have to adapt to the reduced communication channel when major technology infrastructure is down or broken. In addition, VT members may come from various organizational departments, across organizations, and even across countries. Thus, the little experience working with each other may add more challenges to the teams to collaborate smoothly than regular face-to-face teams.

In summary, during crisis, virtual teams' AUITC is a complex and dynamic process and teams may follow different paths in using IT capabilities that support communication, interaction, and team process.

Team Mental Models

Growing attention is paid to how teams gain shared understanding. One manifestation of this concern is the notion of team mental model (TMM). In this stream of research, TMM is suggested as an emergent mechanism that enables the team functioning, adaptability towards team effectiveness. More specifically, TMM refers to "knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behavior to demands of [their unique domain]" (Cannon-Bowers & Salas, 1993, p.228). Research has shown that teams with shared TMMs have stronger adaptability than teams that do not (McNeill, Gkaniatsou, & Bundy, 2014; Turoff, Chumer, Van de Walle, & Yao, 2004).

Previous studies have also found that teams can form three types of mental models, i.e. information technology mental models, taskwork mental models, and teamwork mental models. A team's <u>IT mental model</u> is the knowledge structure and beliefs held by the team about the information technology capabilities, the usage of these capabilities, and the perceived effects of using these IT capabilities (Thomas & Bostrom, 2007). A team's t<u>askwork mental model</u> is the knowledge structure and beliefs held by the team about the task goals, steps to accomplish the tasks, and the technologies used to accomplish the tasks. The <u>teamwork mental models</u> refer to the knowledge structure and beliefs held by the team about the team interaction and team members' roles, skills, and knowledge. Assessment of shared mental models' convergence is mostly focused on measuring the degree to which knowledge structures overlap or are similar among the team members, i.e. SMM similarity (Mohammed, Ferzandi, & Hamilton, 2010).

According to the theory of mental models, all these three dimensions of team mental models influence how teams enact appropriate actions and decision-making in crisis. In addition, TMM development is influenced by the teams' overall experience in response to a crisis. For example, the teams may exhibit different styles of role structure adaptation during crisis.

The interplay of AUIT and TMM

AUIT and TMM are two emergent and intertwined processes. In particular, virtual team members' individual or collective use of technologies are influenced by individual knowledge, previous experience with technology, and team mental models on IT capabilities and the fit between IT capabilities and tasks. Especially during crisis under high ambiguity and stress level, team mental models of IT capabilities and task and team can be instrumental in developing swift and effective responses. At the same time, when the organizational crisis lasts long, i.e. a month or longer, virtual teams can actually enhance their team mental models' similarity and accuracy about the IT capabilities, the task and the team process.

In a previous empirical study, the findings also show that virtual teams can vary in terms of their frequency of team interaction (e.g. communication through email) and the complexity of team interaction (e.g. the number of active team participants).

In summary, the interplay between AUIT and TMM is one important yet understudied mean for us to understand how virtual teams can be effective in crisis.

ORGANIZATIONAL CRISIS RESEARCH AND SOCIOMATERIALITY

Organizational crises happen in certain contexts, a school, a firm, a community, or a country. At the same time, given the advances and ubiquitous nature of information technology (IT), for any given context, IT, work and organizations are distinct but intricately integrated facets. Orlikowski and Scott (2009) assert that "attention has tended to focus on technological effects, occasions of change, or processes of sensemaking and interaction with little recognition of the deeply constitutive entanglement of humans and organizations with materiality." (p.466).

Moreover, technology tends to be invisible in the workplace, and this invisibility limits "our capacity to understand, monitor, reflect on, and change them." (p.467) Thus, consistent with the socialmaterial perspective, we believe that the dynamics of socialmateriality can account for the many far-reaching consequences of IT, and it provides a high-level framework that helps explicate the crisis phenomenon.

Given its origin in organizational studies, socialmateriality has a natural link to the organizational crisis literature. One can easily identify the relevance of the key notions of sociomateriality, e.g. relationality, performativity, and sociomaterial assembleages, in organizational crisis studies. Given the increasingly "digital world", embracing the sociomaterial perspective in studying crisis is an interesting and emerging research direction (Nan & Lu, 2014).

In reviewing the crisis literature, we identify one prominent area of crisis research that is especially suitable to be organized under the "umbrella" of the notion of "sociomateriality" - the notion of enacted sensemaking originally proposed by Weick (1988). In this view, Weick (1988, p.309) contends that "all crises have an enacted quality once a person takes the first action." By enactment, he means the social process by which a "material and symbolic record of action" (Smircich and Stubbart, 1985, p.726) is laid down. The outcomes of such enactment of human and technology are called "residuum" (p.307), which refers to "an orderly, material, social construction that is subject to multiple interpretations." At the same time, sensemaking is recognized as an important cognitive process that occurs during enactment and is defined as (Maitlis, Christianson, 2014, p.67) "a process, prompted by violated expectations, that involves attending to and bracketing cues in the environment, creating intersubjective meaning through cycles of interpretation and action, and thereby enacting a more ordered environment from which further cues can be drawn." Sensemaking can also help "reduce the equivocality of the novelty in that it helps to create shared understanding, making it possible to construct plausible explanations of what happened and why." (Dwyer & Hardy, 2016, p.59)

In the EST perspective, crisis is not managed through either the technology or the human, rather, can only be managed or prevented through an understanding of the entangled relationships between human actions, sense making process and the technology. The EST perspective argues that it is the entanglement between technology and human that cause the crisis and therefore, a good understanding of this entanglement will help to prevent the crisis through uncoupling humans' sensemaking process.

> *"Unwitting escalation of crises is especially likely when technologies are complex, highly interactive, non-routine, and poorly understood. The very action which enables people to gain some understanding of these complex technologies can also cause those technologies to escalate and kill." (Weick, p.308)*

Thus, we can see that in EST, crisis management is not simply a process of managing human factors or viewing technology as a deterministic factor, rather, the relationship between technology and human becomes the "theoretical foci and central explanatory vehicle" of understanding the crisis phenomenon (Orlikowski and Scott, p.456).

Similarly drawing on the relational ontology view of technology infrastructure as fast changing during crisis, Robinson, Maddock, Starbird (2015) examine the relationship between technical infrastructure and humans in the support of improvisation and communication among emergency workers. They acknowledged the fast changing and /or "under pressure to change" in the context of emergency response. Humans are viewed as "infrastructurers"—as designers of their own infrastructures. In their study, they identified human interoperability as one important concept that help explains variances in crisis response effectiveness. They report finding that people with the right tools and expertise provide the interoperability for the underlying information and have a greater chance of helping the team to develop more effective information sharing and attain effective improvisation in emergency response.

Working in the operational risk management domain in a financial organization, Hsu, Backhouse, Silva (2014) took a weak sociomaterial perspective on stressing more of the contextual influence on the relationship between IT and risk management in the financial industry. Basing their study on the Structuration Theory, they argue that the implementation of organizational practice, such as operational risk management (ORM), can be examined through the social structures which is influenced by both technology and organizations. In this study, the relationship between IT and risk management are viewed as entangled with each other. First, the authors recognize that there is an increasingly reliance on IT in the financial sector and such reliance on IT requires more attention to examining the management of operational risk with IT. They further acknowledge the increasing complexities in the use of IT for supporting key financial activities. However, the use of complex IT in financial settings not only prevents the risk but also at the same time can introduce new risks and changes to organizations, e.g. creating new roles and introducing new responsibilities. By examining the relationship between IT and operational risk and how organizations develop appropriate structures accordingly, they view the implementation of ORM as a process of "reflexive monitoring and restructuring of organizational practices" (p.68) and conclude that IT has contingent effects in ORM, particularly on the extant organizational structure and choice of risk management approach.

In a related study on organizational crisis and online communities, Nan and Lu (2014) implicitly took the sociomaterial perspective by seeking to identify the patterns of organizational crisis processes in an online community. Particularly, they found that during crisis, the spontaneous, un-order-seeking individual interactions in response to crisis online communities eventually showed an orderly and rational crisis management process as commonly adopted and found in regular organization. In other words, as concluded by the authors, the micro-level interactions among people and technology can result in macro-level outcomes. Regarding relational ontology, the authors did not view IT as distinct material entities, rather, consistent with the online community research stream, they viewed "technology and humans as coevolving forces in emergency responses. In other words, the relevance of IT is perceived through its actualized affordance that is defined as the realized potential that arises from the relation between actor intentions and technology capabilities (Majchrzak, More, & Faraj, 2012). The authors concluded that IT, i.e. online forum, is more than a platform for information manipulation and decision making but also is an "evolving and generative force" that influence and shape users subsequent actions in response to crisis. Table 2 summarizes the three paper on the three dimensions of sociomateriality. The fourth dimension strong/weak is proposed by Jones (2014)

Table 2. Examples of Crisis Papers Using the Sociomaterial Perspective

	Sociomaterial assembleages	Relationality	Equivalence of IT and Human
Weick (1988)	Agree	NA	Agree
Robinson, Maddock, Starbird (2015)	Agree	Agree	Agree
Hsu, Backhouse, Silva (2014)	Agree	Not agree (contextual factors, such as regulatory matters)	Agree

APPLYING SOCIOMATERIAL PERSPECTIVE IN STUDYING VIRTUAL TEAMS IN CRISIS

"While this reality may be similar to those of other CCUs in other hospitals, the specific local interpenetration of the social and material means that each CCU varies in the activities it carries out, how it fits into the medical system, and its physical setting. Even with a common CIS, the different members of the national usergroup used it in different ways, with different functionalities and different attributes, reflecting such things as local IT infrastructure configurations, staff IT skills, and patient types. Nor were these configurations stable. Rather they continually evolved as social/material conditions changed …." (Jones, 2014, p.912-913)

We believe that the above scenarios also hold true in crisis settings, where virtual teams carry out crisis response activities and make critical decisions by adaptively using IT features, exploring IT tools and at the same time developing their shared understanding on task priorities, task contingencies, time situation, and assessment of crisis severity, etc. In addition, though various IT tools and systems have been developed and adopted by organizations for virtual teams to manage crisis, the outcomes of crises are not a single fixed function of IT and virtual teams, rather it is the product of the "contingent interplay of influences (that are themselves neither purely social or material) as these are enacted in situated practices." (Jones, 2014, p. 915)

Past research on virtual teams has shown that for any virtual team, there are at least exist two critical and emergent processes at play---the development of shared understanding among teams and members and the continuing use and adaptation of IT capabilities. First, teams that can successfully adapt IT tools to task needs can experience enhanced team communication and knowledge management efficacy. Second, virtual teams' development of shared understanding can result in unconscious collaborative activities during emergent events. The first process is referred to as adaptive use of IT (AUIT) and the second process is put under the notion of team mental models (TMM) in this paper. Both of these two processes have been found to significantly affect virtual team's capability in dealing with crisis. However, successful AUIT and TMM can be challenging in virtual teams during crisis due to the fast-moving crisis settings, fear, information overload, and reduced communication channels.

Orlikowski and Scott (2009)'s called for researchers' attention on developing practice theory that identifies "recurrently enacted and patterned set of relations, reproduced over time and space." (p.462). Consistent with this call, in this paper we actualize the sociomaterial assembleages by examining the patterns of virtual teams' interplay between TMM and AUIT in crisis and its relationship with teams' crisis outcomes. Such patterns can capture the regular reciprocal relationship between teams' IT capabilities adaptive use and development of team mental models in crisis. For example, an initial TMM guides the virtual team's choice of IT capabilities that could support the systematic, timely and secure storage and dissemination of information. After that, the continuing use of IT for sharing information influences the development of team mental models in virtual teams. To put it another way, virtual crisis management teams could adaptively use IT capabilities during communication, interaction, and information processing related activities, and therefore rely on IT adaptation to build shared understanding. The virtual teams' development of SMM can affect which IT capability will be used and for what purpose that particular IT capability is used.

Three Implications of the Sociomaterial View for Studying Virtual Teams during Organizational Crisis

We contend that the socialmaterial perspective has three important implications for IS research in crisis. First, the notion of relationality provides a novel ontological view of IT and its context of use. The central idea with a relational ontology is that the social and the material are inherently inseparable. Instead of viewing IT and human (organization) as separated entities, the socialmaterial perspective calls for dissolving the analytical boundaries between technologies and humans (Knorr-Certina, 1977; Latour, 2005; Pickering, 1995; Orlikowski & Scott, 2009, p.455). Further, in a relational ontology the technology and human only exist in relation to each other and acquire their "form, attributes, and capabilities through their interpenetration." (p.456) Following this notion of relationality, we view IT is an integral part of virtual teams functioning anywhere under any circumstances. IT and the human beings involved in virtual teams are inseperable during crisis situation. It is our contention that VTs develop team mental models through enactment of IT capabilities and the adaptive use of IT capabilities shape the development of team mental models during crisis.

A second implication is related to the term performativity, which refers to enactment. Instead of examining a virtual teams' performance, performativity calls our attention to how the assemblage of humans and technologies are "made to work" in a particular setting. A related concept is called practice. The socialmaterial perspective calls for more attention to practice theory - "the scholarly effort of understanding how boundaries and relations are enacted in recurrent activities (p. 462)". This implies that in socialmaterial research, any distinction of humans and technologies is analytical only, and done with the recognition that these entities necessarily entail each other in practice" (Orlikowski & Scott, 2009, p.455-456). From the practice lens, researchers recognize organizations as a "recurrently enacted and patterned set of relations, reproduced over time and space" (Orlikowski & Scott, 2009, p.462). Identifying an encompassing, systematic "practice theory" is suggested to be the most effective way of framing and orienting research. In our research, we contend that the dynamics of the entanglement of the IT and team in crisis reveals the reality which they describe. Our search for the patterns of such dynamics through an analysis of the interplay between VTs and the IT used will contribute to generate practice theory in crisis.

Finally, the notion of socialmaterial assembleages (rather than either discrete entities or mutually dependent ensembles) is the cornerstone of our research motivation that focuses on the interplay between AUIT and TMM development in crisis situations. In our research, we have found that IT capabilities and team mental model (TMM) development are entwined all together. Further, we hold the assumption that such entanglement between technology capabilities and team mental models development in crisis are varied in different virtual teams based on the type of crisis. We describe these socialmaterial assembleages of technology and humans (virtual team members), in terms of the notion of "interplay of AUIT and TMM". Following Orlikowskid & Scott, we describe this interplay in terms of interesting patterns set in the context of the crisis phenomenon.

A METHOD FOR DESCRIBING SOCIOMATERIAL ASSEMBLEAGES FOR VTs AND ORGANIZATIONAL CRISIS

A challenge of sociomaterialists lays in the balance of rigor and relevance when developing the "recurrent patterns" of IT and organizations. In fact, in their review of the sociomaterial approach studies, Cecez-Kecmanovic et al. (2014) found that most of the study predominantly describe the organizations while taking IT as a much more subordinate or even silent role in the "entanglement". They suggest that to fully capture the entanglements between human and technology following the sociomaterial view, one should avoid only using one single case study.

Two categories of promising research methods as suggest by Cecez-Kecmanovic et al. (2014) exist. One category is called the "flexible computational approach" that can integrate both digital traces and computational methods. The other approach is the "practice-oriented sociomaterial methodology", which aims at developing an appreciation and articulation of the dynamics of practice following an iterative process of "zooming in" and "zooming out" (cite). Both of these approaches emphasize the discovery of recurrent patterns. However, the challenge of applying the first category approach lay in the accessibility to large scale of valid and reliable digital-trace data and a careful operationalization of the constructs of interest to the variables. With regard to the second approach, i.e. "practice-oriented sociomaterial methodology", as said by Cecez-Kecmanovic et al. (2014), there is no step-by-step action list for extracting and describing the patterns, instead, one should use as a general approach in guiding one's study in his/her own study context.

Considering the challenges of the above two approach and the purpose of our research interest, we propose an adaption of a systematic method for discovering effective patterns proposed by Khazanchi and Zigurs (2011). Adopting the grounded theory approach, i.e. a theory driven and bottom-up approach, Khazanchi and Zigurs (2009) identified a number of useful patterns for various types of virtual team projects (i.e. lean, hybrid, and extreme) with the aim of better understanding the effectiveness and ineffectiveness of virtual projects management and IT capabilities usage.

As a result of their study, they give specific suggestion on the contents of patterns as well as the methods for extracting these patterns. Specifically, patterns are made up of five components: "(1) the pattern's name-a descriptive word or phrase that captures its essence; (2) the context – a description of the situation to which the pattern applies; and (3) the problem – a question that captures the essence of the problem that the pattern addresses; (4) the solution – a prescription for dealing with the problem; and (5) an optional discussion – any additional information that might be useful in applying the pattern" (p.6). Khazanchi and Zigurs also propose five steps for systematically discover patterns. We summarize the five steps along with their explanations in Table 3.

Table 3. Five Steps for Discovering Patterns (Khazanchi and Zigurs, 2011)

Sequence of Step	Explanation
Step 1: Recognize and abstract candidate pattern	Examine the data collected and develop understanding on the meaning of the lessons learned from characteristics that result in effective virtual project management practices.
Step 2: Define recurring problem	Develop a simple question to address the specific feature or set of features solved in each of the candidate patterns generated in the first step one by one.
Step 3: Define context	For each of the candidate patterns, add the description of the situation to which the pattern frequently applies.
Step 4: Name and describe pattern	Name the pattern so that it can be explained to and shared with others.
Step 5: Validate and refine pattern	Validate the patterns in new context.

Consistent with the sociomaterial view, Cecez-Kecmanovic et al. (2014, p.821) argue that these are "not a few stable patterns but many unique patterns". Considering the interplay of AUIT and TMM development in virtual teams during crisis, we propose that the many unique patterns can be understood as effective practices within virtual teams entail decisions about how to best apply different technology capabilities for effectively develop team mental models during crisis. To this end, we believe that this practice-oriented method proposed by Khazanchi and Zigurs (2006) provides us a balanced method of rigor and relevance and can help us to develop the recurrent patterns of the interplay of AUIT and TMM with adequately addressing the crisis context where virtual teams reside in.

We believe that this approach is scalable and can be effectively used to describe the patterns of sociomaterial assembleages that occur during organizational crisis.

CONCLUSION

This paper identifies a new theoretical lens, i.e. sociomateriality to study distributed teams involved in managing organizational crises. In addition, we recommend using patterns to document and describe practices associated with the sociomaterial assemblages for virtual teams in crisis settings. We believe that this approach represents an important foundational step towards examining explicitly "constitutive entanglement" within a specific context, i.e. crisis domain. Based on our prior research on virtual teams, we posit that patterns of effective virtual team management in crisis settings can be identified and documenting using a sociomaterial lens. Our next goal is to conduct an empirical study in organizational settings.

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MAY 21 - 24, 2017

ISCRAM 2017

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Proceedings of the 14th International Conference on Information Systems for Crisis Response and Management

ISSN : 2411-3387

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