International Journal of Human–Computer Interaction

ISSN: 1044-7318 (Print) 1532-7590 (Online) Journal homepage: http://www.tandfonline.com/loi/hihc20

Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research

Christian Reuter, Amanda Lee Hughes & Marc-André Kaufhold

To cite this article: Christian Reuter, Amanda Lee Hughes & Marc-André Kaufhold (2018): Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research, International Journal of Human–Computer Interaction, DOI: 10.1080/10447318.2018.1427832

To link to this article: https://doi.org/10.1080/10447318.2018.1427832

Published online: 24 Jan 2018.

INTERNATIONAL JOURNAL OF HUMAN–COMPUTER INTERACTION
https://doi.org/10.1080/10447318.2018.1427832

Social Media in Crisis Management: An Evaluation and Analysis of Crisis Informatics Research

Christian Reuter [a], Amanda Lee Hughes[b], and Marc-André Kaufhold[a]

[a]Technische Universität Darmstadt, Science and Technology for Peace and Security (PEASEC), Darmstadt, Germany; [b]Computer Science Department, Utah State University, Logan, UT, USA

ABSTRACT

Since the terrorist attacks of 9/11, the use of social media in emergency and crisis events has greatly increased and many studies have concentrated on the use of ICT and social media before, during, or after these events. The field of research that these studies fall under is called *crisis informatics*. In this article, we evaluate and analyze crisis informatics research by looking at case studies of social media use in emergencies, outlining the types of research found in crisis informatics, and expounding upon the forms of interaction that have been researched. Finally, we summarize the achievements from a human–computer interaction perspective and outline trends and challenges for future research.

1. Introduction

Social media enable increased communication and collaboration among online users, and they have become a ubiquitous part of everyday life for many. The most common social media platforms attract a large number of users: In August 2017, Facebook had about 2.0 billion, YouTube 1.5 billion, WhatsApp 1.2 billion, Instagram 700 million, Twitter 328 million, and LinkedIn 106 million active users.[1] With such pervasiveness, people use social media not only in everyday life but also during crisis and emergency events. One of the earliest example of this kind of social media use occurred during the 9/11 attacks in 2001. During these attacks, the Federal Emergency Management Agency (FEMA) and the Red Cross employed web-based technologies to disseminate information to the public and to report the status of the relief efforts externally and internally (Harrald, Egan, & Jefferson, 2002). Additionally, citizens created wikis to gather information about missing persons (Palen & Liu, 2007).

Since about 2006, the use of social media in managing crisis events has gained increasing interest among researchers. This area of study is often called *crisis informatics*. Established by Hagar (2007) and later expanded upon by Palen, Vieweg, Liu, and Hughes (2009), crisis informatics "views emergency response as an expanded social system where information is disseminated within and between official and public channels and entities." 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).

The purpose of this article is to review the crisis informatics research literature, report trends, and offer perspective on the future of this research. We begin with an overview of the many case studies of social media use in emergencies (Section 2). Many crisis informatics studies focus on specific events, such as the 2013 European floods (Reuter, Ludwig, Kaufhold, & Pipek, 2015a), the 2011 London riots (Denef, Bayerl, & Kaptein, 2013), or the 2012 Hurricane Sandy (Hughes, St. Denis, Palen, & Anderson, 2014). We provide a sample of the many different kinds of events that have been studied and summarize trends across these events. Next, we examine the different types of research that can be found in the crisis informatics literature with the aim of helping the reader understand the most common approaches to research in this area (Section 3). We then break down the literature by the different types of interaction studied and derive use patterns (Section 4). Finally, we discuss future directions for this research (Section 5).

2. Case studies of social media in emergencies

The World Disaster Report (IFRC, 2015) states that in the last ten years there have been an average of 631 disasters per year, including 83,934 deaths, 193,558 persons affected, and estimated damage of 162,203 million US dollars per year. Since 2001, social media have played an increasingly important role in how people respond to and communicate around these world-wide disasters. For example, people used photo-repository sites for information exchange after the 2004 Indian Ocean tsunami (Liu, Palen, & Sutton, 2008) and the 2007 Southern California wildfires (Shklovski, Palen, & Sutton, 2008). A prior study on Hurricane Katrina in 2005 looked at

CONTACT Christian Reuter reuter@peasec.tu-darmstadt.de

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/hihc.

the use of online sites that help people find others (PeopleFinder) and places to stay (ShelterFinder) (Murphy & Jennex, 2006). What these studies have in common is that they demonstrate how social media have become an evolving and meaningful form of backchannel communication and public participation for disaster events (Palen, 2008). Here, we take a closer look at the many different disaster events that have been the subject of crisis informatics research.

2.1. Overview of case studies

Table 1 provides a chronological overview of studies regarding social media use across a wide variety of emergency and disaster events[2]. When compiling this list, the emphasis was to provide a representative sample of the types of events that have been studied since 2001. It was not our aim to provide a comprehensive list of all the research on this topic. Following the methodology of vom-Brocke, Simons, Riemer, Niehaves, and Plattfaut (2015), we used Google Scholar to identify research studies by searching for the keywords "social media", "web 2.0", "Twitter", "Facebook", "emergency", "disaster", and "crisis" in singular and plural forms without temporal limitations. Additionally, we used backward and forward searches. For larger, more well-known crises, we concentrated on studies about the use of social media while using a search term for that event (e.g., Paris shootings 2015). While we oriented our literature review on methodological guidelines, our aim was not to conduct a systematic literature review as such (e.g., with a selection of journals and conferences and the sole consideration of papers found using search terms). Our aim was more to comprehend the development of an emerging field (crisis informatics) among different terms, journals, and disciplines. Table 1 gives an overview of the cases we found during our literature review and serves as a summary. The studies are sorted by the year of occurrence, with each study listing a reference, the event that was examined and the contribution of the study. Several of these studies are analyzed more thoroughly in the following chapters.

2.2. Summary of case studies

When looking at these case studies, we observe several trends. First, there is wide diversity in the different types of events that have been studied, with the representation of both human-induced disasters (e.g., shootings, terror attacks, political uprisings) and natural hazards (e.g., tsunamis, hurricanes, earthquakes, floods). As more events are studied, we can better understand how social media are used in different types of disaster events. This diversity also allows researchers to look for patterns or trends in the research by comparing how social behaviors might differ from each other or resemble one another across events.

Second, most studies listed here (and in the crisis informatics literature more generally) concentrate on Twitter as a medium of study (Hughes, Starbird, Leavitt, Keegan, & Semaan, 2016). While Twitter is a popular social media site (~328 million users), other social media sites, such as Facebook with 2.0 billion active users, attract more users. But why is Twitter still the focus of so many crisis informatics studies? There are several reasons for this inconsistency. First, it is easier for researchers to obtain public data from Twitter than from other sources. Twitter has a public API and more open terms-of-use agreements for how its public data can be used. Obtaining a statistically sound data sample is also easier to achieve with Twitter (Reuter & Scholl, 2014). Moreover, limitations on the amount of content that can be contained in each message (140 characters) make Twitter messages easier to store, process, and analyze. While a growing number of studies looks at social media data beyond Twitter, most of the research only focuses on Twitter, which is a limitation of the crisis informatics literature.

Finally, these case studies reflect a bias toward the study of US-based events as well as the examination of social media data in the English language. The focus on US-based events has largely been a result of who has conducted the research; researchers tend to study events they have ready access to, and in the early years, most of the crisis informatics research was carried out by US researchers. Over time the research field has attracted researchers from around the globe, and thus a wider variety of international disaster events have been studied (see Table 1). The abundance of research on English-language social media data is a more pronounced trend that continues to persist. Again, this trend is mostly a result of who is performing the research (i.e., English-speaking researchers), but also a reflection of the techniques and tools that researchers use to make sense of this data. For example, Natural Language Processing (NLP) techniques are far more developed and sophisticated for the English language. This gap is important to fill but requires ongoing efforts from those who either know other languages or have access to translation services which can make the research cost prohibitive.

3. Types of crisis informatics research

In this section, we describe four broad types of research commonly found in the crisis informatics literature. Based on analysis of the studies in Section 2, we identified and clustered the different types of research used in these studies. The clustering process was informed by our knowledge of the field of crisis informatics which has been shaped through many years of conducting our own research in the area and reviewing papers written by other crisis informatics researchers. These types are not meant to be inclusive of all possible research in the field, but rather to serve as a guide for understanding the typical scope and variety of research that has appeared in relevant conferences, such as the Information Systems for Crisis Response and Management (ISCRAM) conference, and research publications, including diverse special issues on the topic in international journals (Hiltz, Diaz, & Mark, 2011; Pipek, Liu, & Kerne, 2014; Reuter & Mentler, 2018; Reuter, Mentler, & Geisler, 2015b). These types of research employ different methods and approaches and reflect the multi-disciplinary nature of crisis informatics research.

3.1. Empirical investigation of social media use

The focus of empirical work in crisis informatics has been to observe and enumerate how social media are used and the

Table 1. Overview of case studies in the research literature, enhancement of Reuter and Kaufhold (2018).

Event of Study	Contribution	Reference
2001 9/11	Describes the use of wikis to collect information about missing people.	Palen & Liu (2007)
	Explains how FEMA and the Red Cross used web-technologies to inform the public and to provide status reports.	Harrald et al., 2002)
2004 Indian Ocean tsunami	Describes citizens' use of photo repository sites to exchange information.	Liu et al. (2008)
2005 Hurricane Katrina, 2010 volcano Eyjafjallajökull in Iceland	Shows that the credibility of social media information is less than that of printed, official online or televised news and information from family, relatives, or friends.	Endsley, Wu, Reep, Eep, & Reep (2014)
2007 Southern California wildfires	Describes how citizens use social media to seek and share information that builds community during a disaster event.	Shklovski et al. (2008)
2007 Southern California wildfires	Suggests that community information resources and other backchannel communications activity enabled by social media are gaining prominence in the disaster arena.	Sutton, Palen, & Shklovski (2008)
2008 Hurricanes Gustav and Ike	Highlights differences between the use of Twitter in crises and general use.	Hughes & Palen (2009)
2008 Sichuan earthquake	Outlines how people gather and synthesize information through social media.	Qu et al. (2009)
2008 Tennessee River technological failure	Describes how official responders broadcast emergency-relevant information via Twitter.	Sutton (2010)
2009 Lakewood attack on police officers	Shows how people use Twitter to organize and disseminate crisis-related information.	Heverin & Zach (2010)
2009 Oklahoma fires	Discusses the role of retweeting for information processing, especially filtering and recommendation.	Starbird & Palen (2010)
2009 Red River floods	Delineates the different ways people use social media during an event, including information broadcasting, directing, relaying, synthesizing, and redistributing.	Vieweg et al. (2010)
2010 earthquake in Chile	Shows that the propagation of tweets that correspond to rumors differs from tweets that spread news because rumors tend to be questioned more than news by the Twitter community.	Mendoza et al. (2010)
2010 Bornholm blizzard	Examines two Facebook groups and finds that geographical location and self-selection into groups creates different views of a crisis.	Birkbak (2012)
2010 Deepwater Horizon oil spill disaster	Demonstrates that BP's corrective action as the dominant image restoration strategy caused high presence of negative emotion.	Muralidharan, Dillistone, & Shin (2011)
2010 Haiti earthquake	Analyzes how people helped translate information during the earthquake and reveals the phenomenon of "digital volunteers".	Starbird & Palen (2011)
2010 Love Parade mass panic in Germany, volcano Eyjafjallajökull in Iceland	Systematizes the communication between authorities and citizens during emergencies, outlining the need for duplex communication.	Reuter et al. (2012)
2010 Haitian earthquake	Presents a case study of how social media technologies were used and how they influenced knowledge sharing, reuse, and decision-making.	Yates & Paquette, (2011)
2010 San Bruno Californian gas explosion and fire disaster	Illustrates that sentiment analysis (analysis for identifying and extracting subjective information) with emotions performed 27% better than Bayesian Networks alone.	Nagy, Valley, & Stamberger (2012)
2011 large-scale fire in Moerdijk, the Netherlands	Explains that most tweets do not contain new relevant information for governments; tweets posted by governments were buried in an avalanche of citizen tweets.	Helsloot & Groenendaal (2013)
2011 Egyptian uprising	Shows how the crowd expresses solidarity and does the work of information processing through recommendation and filtering.	Starbird & Palen, (2012)
2011 Great East Japan earthquake	Emphasizes the use of Twitter to provide emotional support and mentions the problem of widely publishing obsolete or inaccurate information and the unequal distribution of useful information.	Wilensky (2014)
2011 Norway attacks	Finds that the notion of peripheral response has evolved in relation to emergent forms of agile and dialogic emergency response.	Perng et al. (2012)
2011 San Diego/Southwest blackout	Discusses the limitations of using social media to contact friends and family when the cell phone network did not function as expected.	Jennex (2012)
2011 Shadow Lake fire	Analyzes the deployment of trusted digital volunteers as a virtual team to support an incident management team.	Palen, St. Denis, & Hughes (2012)
2011 Super Outbreak	Distinguishes groups of twitterers, such as helpers, reporters, retweeters, and repeaters.	Reuter et al. (2013)
2011 Tunisian revolution	Describes how social media linked young activists with actors in other cities and stimulated participation in weekly demonstrations.	Wulf, Misaki, Atam, Randall, & Rohde (2013)
2011 Escherichia coli contamination crisis	Illustrates how social media can act as a complementary information channel, but that it is not a substitute for traditional or online media.	Kuttschreuter et al. (2014)
2011 Fukushima Daiichi nuclear disaster	Contrasts effects of medium and crisis type in an online experiment.	Utz et al. (2013)
2011 Tohoku earthquake and tsunami Japan	Sent open-ended questionnaires to a randomly selected sample of Twitter users and analyzed the tweets sent from the disaster-hit areas.	Acar & Muraki (2011)
2012 hurricane Isaac	Demonstrates which classification algorithms work best in each phase of emergency.	Yang, Chung, Lin, Lee, & Chen (2013)
2012 hurricane Sandy	Shows that few departments used online channels in their response efforts and that communication differed between fire and police departments and across media types.	Hughes et al. (2014)
2012 Madrid Arena tragedy	Discusses opportunities for social media to support local communities using the Crisis Communication Management theory.	Medina & Diaz (2016)
2013 Colorado flood	Highlights the blending of online and offline expertise to evacuate horses from an isolated ranch.	White & Palen (2015)
2013 European flood in Germany	Identifies challenges of public response among emergent groups and digital volunteers, highlighting the role of moderators.	Kaufhold & Reuter (2014)
2013 European flood in Germany	Finds that messages from users located near severely flooded areas have a much higher probability of being relevant.	De Albuquerque et al. (2015)
2013 Woolwich (London) terrorist attack	Shows that the sentiment expressed in tweets is significantly predictive of both size and survival of information flows.	Burnap et al. (2014)
2014 Carlton Complex Wildfire	Examines who contributes official information online during a crisis event and the timelines and relevance of the information provided.	Chauhan & Hughes (2017)
2014 Sydney siege	Provides a system to analyze posts about a special topic and visualize the emotional pulse of a geographical region.	Wan & Paris (2015)
2015 cyclone Pam 2014 Kashmir floods, Indonesia landslide	Collects data via Twitter for exploration of the ICT infrastructure for disaster management.	Chaturvedi, Simha, & Wang (2015)

(*Continued*)

Table 1. (Continued).

Event of Study	Contribution	Reference
2014 Ebola fear in the USA	Examines the amplified fear of the imported Ebola virus through social media.	Fung, Tse, Cheung, Miu, & Fu (2014)
2015 Amtrak derailment, Baltimore protests, hurricane Joaquin floods	Examines the use of the live-streaming application Periscope by both citizens and journalists for information sharing, crisis coverage and commentary.	Fichet et al. (2015)
2015 Nepal earthquake	Investigates the work of mapmakers and outlines factors contributing to the emergence of infrastructure around their work practice.	Soden & Palen (2016)
2015 Nepal earthquake, 2013 Philippines typhoon, 2011 Japan tsunami	Investigates how "Ambient Geographic Information" via social media (Twitter and Flickr) can be used in crisis management.	Zipf (2016)
2015 Charlie Hebdo shooting	Examines sociological theories in terms of the social factors that contribute to online individual behavior.	An, Kwak, Mejova, & Oger (2016)
2015 Tianjin blasts	Provides a clustering analysis and time series analysis of social network Weibo's rumor management strategies.	Zeng, Chan, & Fu (2016)
2015 Paris shootings	Examines the velocity of newsworthy content and its veracity with regard to trusted source attribution.	Wiegand & Middleton (2016)
2016 Roanu cyclone in Sri Lanka	Explains how Twitter and Facebook were used to help flood-affected victims with disaster warnings, relief information, and weather alerts.	Sagar (2016)

many different types of behaviors that social media can support. Most studies of this type collect social media datasets concerning a particular disaster event or user group and then analyze these datasets looking for patterns or interesting phenomena.

Empirical investigation in crisis informatics was particularly common when social media were new, and researchers were still trying to figure out how they could be used during a crisis event (Palen & Liu, 2007). Through these early empirical investigations, most of which are descriptive in nature, researchers learned much about how social media are used during emergencies. For instance, researchers discovered that social media have increased the rate and scale at which information seeking and production can take place (Hughes, Palen, Sutton, Liu, & Vieweg, 2008; Palen & Liu, 2007). Emergency responders use social media as a means to communicate with the public by distributing important information and making themselves available for questions and feedback (Hughes & Chauhan, 2015; Hughes et al., 2014). Responders also increasingly use social media as a way to understand the public information space around a crisis – looking for information that could help in response efforts as well as false rumors and misinformation that need correction (Andrews, Fichet, Ding, Spiro, & Starbird, 2016; Denef et al., 2013; Hiltz, Kushma, & Plotnick, 2014; Hughes & Palen, 2012; Latonero & Shklovski, 2011; Sutton et al., 2012). Those directly affected by a crisis event seek, provide, and exchange information through social media as they attempt to rapidly assess the impact of the event on themselves and their social network, determine what to do, and meet the needs of others affected with information and other types of assistance (Bruns & Burgess, 2012; Hughes et al., 2008; Liu et al., 2008; Palen et al., 2009; Perng et al., 2012; Qu, Wu, & Wang, 2009; Semaan & Mark, 2012; Starbird, Palen, Hughes, & Vieweg, 2010). Interested members of the public outside the impacted area can monitor the event from around the world using social media (Bruns & Burgess, 2012), which has enabled groups of interested bystanders to help in the response, relief, and recovery efforts through acts of digital volunteerism (Starbird & Palen, 2011).

As empirical work in crisis informatics matured beyond the initial focus of what social media could do, researchers began to look more deeply at the socio-technical phenomenon and challenges that were introduced by social media. For example, a number of research studies employed interviews and surveys with emergency responders to better understand the challenges responders face when using social media (Hughes & Palen, 2012; Latonero & Shklovski, 2011; Plotnick, Hiltz, Kushma, & Tapia, 2015). Such challenges include the lack of organizational support, poor training, and insufficient time and resources. Several studies tried to understand how citizens perceive social media communications in emergencies (American Red Cross, 2012; Canadian Red Cross, 2012; Flizikowski, Hołubowicz, Stachowicz, Hokkanen, & Delavallade, 2014; Reuter & Spielhofer, 2017). Other research explored what kinds of citizen-generated social media information could contribute to situational awareness around a crisis event and how that information could be extracted and used (Cameron, Power, Robinson, & Yin, 2012; Vieweg, Hughes, Starbird, & Palen, 2010). Another rich area of research centered on understanding the credibility of social media sources and the information they provide (Arif et al., 2016; Castillo, Mendoza, & Poblete, 2011; Starbird, Maddock, Orand, Achterman, & Mason, 2014; Tapia, Moore, & Johnson, 2013). Such research seeks to detect and prevent/correct false rumor and misinformation that could be damaging to crisis response and relief efforts. As a last example, many empirical studies assess and analyze the uses and effectiveness of different social media platforms, such as Flickr, Twitter, Facebook, and Periscope (Fichet, Robinson, & Starbird, 2015; Hughes et al., 2014; Liu et al., 2008).

The empirical investigations discussed in this section often tie to human-computer interaction (HCI) traditions of understanding users and user behavior – giving us insight into how we might build and shape future technologies, as well as how human processes and practices might be better adapted to work with social media technologies.

3.2. Collection and processing of social media data

The crisis informatics research in this category focuses on collecting, sorting, and making sense of the large amounts of social media data that people generate regarding a crisis event (Castillo, 2016). Making appropriate choices about how to collect relevant social media data can be challenging, and study of large-scale datasets requires increasingly

sophisticated software infrastructure to collect and store the data (Anderson & Schram, 2011). Keywords and hashtags are often used to find relevant messages to study, but there are limitations to this approach because the queried keywords and hashtags may not be explicitly included in messages about an event and they tend to evolve over time (Reuter et al., 2016c). One approach for finding relevant social media data is to search for messages that originate from the location of study. However, only a small subset of social media data contains geo-location information, so samples collected in this manner are necessarily limited. Temporal problems with data collection can also arise, because social media data is often ephemeral and access to the data can quickly disappear if it is not collected right away – furthermore less and less data is provided by some services (Reuter & Scholl, 2014). Some meta-data (EXIF data with pictures) are no longer provided or services ask for payment to provide them. When collecting social media data to study, researchers must carefully consider these challenges and choose research questions that can be answered given the limitations of the collected data.

Researchers employ a variety of methods for processing social media data, including NLP techniques, machine learning classification, and visual analytics (Imran, Castillo, Diaz, & Vieweg, 2015). The goal of this type of research is to make data more accessible and to provide solutions that can help people make sense of data in real-time. Among others, these methods aim on *filtering* social media streams (e.g., to reduce irrelevant information or spam), *detecting* new events or *monitoring* ongoing events (e.g., to assess the spread of an infectious disease), *identifying* relevant topics in online public communication (e.g., the current situation, emotional support, financial or material aid, ongoing response actions or water levels during a flood), *classifying/clustering* social media items into one or more categories (e.g., in terms of content, source, credibility, time, or location), or *interacting with/visualizing* results of analyses in a useful manner (e.g., displaying indicators in customizable diagrams, geolocations on a map, and important metadata, such as photos or videos, in specific views). Despite growing usefulness and accuracy of these approaches, there are still many challenges for this kind of research. For example, computational processing and analysis are difficult to do in real-time. Most research is done post hoc, months or even years after the occurrence of the event, which limits the usefulness of the research findings for more current events. Thus, moving toward real-time analysis is an important goal for this type of research. Researchers are also seeking ways to improve the classifying process and better sort and filter relevant information. Accuracy varies widely, and it is unlikely that a single approach will work for all types of events; it likely needs to be adapted to fit the context of the crisis event being monitored. Another big challenge is to detect malicious behavior, identifying false rumor, and misinformation (Starbird et al., 2014).

Researchers have developed several systems that employ these data processing techniques to make useful information more readily available to emergency responders and members of the public (Caragea et al., 2011; Imran, Castillo, Lucas, Meier, & Vieweg, 2014; Yin, Lampert, Cameron, Robinson, & Power, 2012). We discuss development of such systems in more detail in the next section.

3.3. System design, building and evaluation

Another common type of crisis informatics research is one where researchers design, build, and/or evaluate technical solutions that address the problems that users encounter with social media during a crisis event. These solutions encompass a growing number of systems that originate from research in fields such as Computer Science and HCI.

When designing systems, researchers have taken different approaches. Some researchers take a participatory approach, where the potential users of the system are directly involved in the design process as co-participants (Hughes, 2014; Hughes & Shah, 2016; Kristensen, Kyng, & Palen, 2006). Other researchers engage in more theoretical design work. In this kind of work, researchers propose a model or framework for understanding social media communications in crises (Liu, 2014; White & Plotnick, 2010). These models or frameworks typically lead to design implications and recommendations for systems that support social media use in a disaster.

Examples of systems that have been built include a growing number of public, scientific, and commercial applications for managing social media in crisis. Pohl (2013) compares and classifies these applications by whether they (a) consider one or several social media platforms for monitoring, (b) were directly or indirectly developed for crisis management, and (c) perform different kinds of analysis, such as monitoring or sentiment analysis. Many systems support some of these requirements (e.g., Ushahidi (Okolloh, 2009), TweetDeck (Twitter, 2014), Twitcident (Terpstra, De Vries, Stronkman, & Paradies, 2012), Tweak the Tweet (Starbird & Stamberger, 2010), TwitInfo (Marcus et al., 2011), SensePlace2 (Robinson, Savelyev, Pezanowski, & MacEachren, 2013), XHELP (Reuter et al., 2015a), CrowdMonitor (Ludwig, Siebigteroth, & Pipek, 2015), and PIO Monitoring Application (Hughes & Shah, 2016)). However, these systems are limited as many of them have syntactical requirements for the user, do not provide cross-platform structures, just focus on Twitter (Marcus et al., 2011; Terpstra et al., 2012), or require the use of a new platform and therefore fail to integrate ICT into existing networks (Marcus et al., 2011; McClendon & Robinson, 2012; Robinson et al., 2013; Terpstra et al., 2012; Twitter, 2014). Thus, there continues to be a need for new and improved systems that support social media use in times of crisis.

After these systems are built, they are usually tested with their target audience. Evaluation procedures vary widely. Often, evaluation is limited, done in a tightly controlled environment or a less than realistic situation (e.g., a simulation). Other times, evaluation takes place during an actual event. Unfortunately, testing during an actual emergency event can be challenging since emergency responders typically do not want to rely on an untested system. Therefore, researchers must focus on establishing relationships with emergency responders before an event begins so that the responders will trust them enough to use a new, untested system (Hughes & Shah, 2016).

3.4. Cumulative and longitudinal research

Now that the field of crisis informatics has begun to mature, works that summarize or synthesize existing research into new theoretical or practical perspectives have appeared. These works include research survey articles like this one and others (Hughes et al., 2014; Veil, Buehner, & Palenchar, 2011) that orient practitioners and researchers to the field of crisis informatics and the developments found there. Synthesizing research also includes papers that focus on summarizing research around a particular problem, such as the issue of including the work of digital volunteers into formal response work (Hughes & Tapia, 2015) or the challenges of processing and making sense of large amounts of social media data in crisis (Imran et al., 2015). These are usually problems that cannot be solved with one study and so, it is important to draw conclusions across a wide body of research.

The field of crisis informatics has accumulated a large enough body of research that longitudinal research is starting to become possible. Such research promises to answer questions such as the following: How do people use or not use social media during different types of crisis events (e.g., terrorist attacks, hurricanes, wildfire, etc.)? What types of social media are more or less effective for emergency management? Nonetheless, longitudinal research can still be challenging to conduct because social media platforms continue to rapidly evolve and the context in which the platforms are used also change quickly. For instance, different platforms grow and ebb in popularity based on location, time or other social factors. Thus, it is important that crisis informatics researchers distinguish between findings that are generalizable versus those findings that are tied to a specific social media platform or crisis context.

3.5. Summary of research types

The research covered in this section of the article is meant to give the reader perspective on the different kinds of research typically found in the field of crisis informatics. The research employs a wide array of methods and techniques that fall across a variety of academic disciplines. For instance, much of the empirical work (e.g., social media content analysis, interviews with social media users, etc.) is conducted by social science researchers or those who use social science methods (e.g., HCI or information science researchers). The application of big data methods to issues of social media use in crisis tends to come from computational scientists in fields like computer science and data science. Researchers in fields like computer science and HCI are typically the ones that build and evaluate systems that support social media use during crisis events. Because the field of crisis informatics is multidisciplinary, relevant research can be diffuse and difficult to find, appearing in the journals, conferences, and other publication venues of the many disciplines that engage in this research. The diversity of crisis informatics research highlights the importance of inter-disciplinary publication venues, such as the ISCRAM conference, that bring together researchers from different disciplines to discuss common concerns and research interests. Here, we have discussed what academic disciplines engage in crisis informatics research and provided examples so that the reader can better understand the scope of research done in the area and where to find it.

4. Types of interaction: usage patterns in crisis informatics

Another way to understand the crisis informatics literature is to distinguish between different types of use. We refer to these different types as usage patterns (Reuter & Kaufhold, 2018). The use of social media requires classification due to the range of diverse emergencies and their responses. Classification can facilitate the utilization and development of qualified technology and promote interaction and systematic analysis of behaviors. Reuter, Marx, and Pipek (2012) created a classification matrix for cooperation in crises, which depends on the sender (X-axis) and the recipient (Y-axis) of digital content. Considering citizens (C) and authorities (A), such as emergency services, the crisis communication matrix differentiates between four observed information flows or patterns of social media use in emergencies (Figure 1).

At the inter-organizational level, crisis response organizations communicate with each other (A2A). Citizens and volunteers communicate with each other face-to-face or virtually via social media such as Facebook or Twitter on the public level (C2C). Crisis response organizations investigate this citizen-generated content (C2A). Not only do citizens talk to each other but also the organizations responsible for recovery work keep the public up-to-date (A2C).

The four categories in Figure 1 are based on the "categories of organizational behavior" of Quarantelli (1988). The 2 × 2 matrix is a simplification of reality. While many crisis actors are clearly authorities or members of the public, others, such as digital volunteers, may fall under either category depending on the context. We may consider additional categories in future work but to keep our analysis manageable, we chose to work with this 2 × 2 matrix.

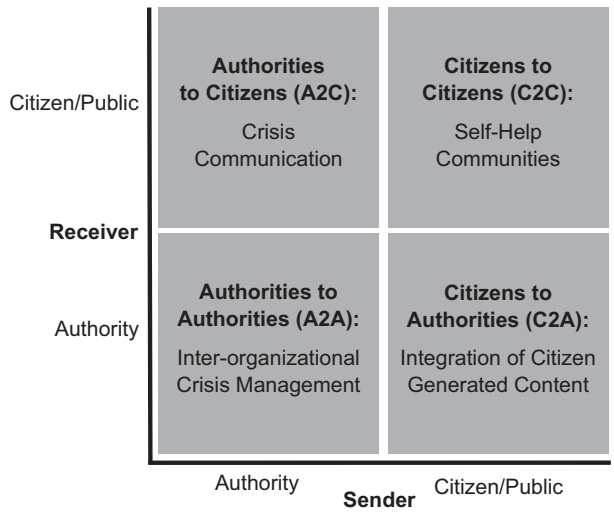

Figure 1. Crisis communication matrix (Reuter et al., 2012), terminology has been adapted to fit the context of this paper.

In the following sections, we discuss each of the four classifications in the Crisis Communication Matrix (see Figure 1) in more detail and offer examples of crisis informatics literature that falls into each of these classifications.

4.1. From citizens to citizens (C2C) – self-help communities

Most of the content generated by citizens through social media is intended for other residents and not necessarily for emergency services. Social media enable people to help each other and to coordinate among themselves, but these types of activities are not new. Quarantelli and Dynes (1977) and Stallings and Quarantelli (Stallings & El Quarantelli, 1985) describe "emergent groups" like these as "private citizens who work together in pursuit of collective goals relevant to actual or potential disasters but whose organization has not yet become institutionalized." Quarantelli (1984) defines important conditions for the emergence of such groups: a legitimizing social environment, the availability of specific non-material resources, a perceived threat, a network of social relationships, and a supporting social climate. Research has found that citizens can significantly contribute to rescue and response work because, contrary to popular opinion, they tend to react rationally to a crisis, rarely panic or loot, and are not helpless (Helsloot & Ruitenberg, 2004). In this context, Reuter et al. (Reuter, Heger, & Pipek, 2013) differentiate between activities in the 'virtual' online world and the physical location of a disaster. Virtual "digital volunteers" (Starbird & Palen, 2011) work primarily online, while on-site "emergent groups" (Stallings & El Quarantelli, 1985) normally work at the physical site of the crisis event.

Several studies have examined citizens' and communities' activities in social media during emergencies. One study that concentrates on hurricanes Ike and Gustav from 2008 distinguishes between the use of Twitter in crisis and non-crisis times and reports that information brokerage and broadcasting can be found more often in Twitter use during crises (Hughes & Palen, 2009). During the 2008 Sichuan earthquake, people collected and synthesized information (Qu et al., 2009). A study about the Tennessee River technological failure in 2008 discovers that social media could be used to raise emergency awareness among citizens and exceed the boundaries of locally limited networks (Sutton, 2010). During the Yushu earthquake in 2010, people used microblogging to obtain information about people or the status of the emergency (Qu, Huang, Zhang, & Zhang, 2011). Another study shows that, after the 2011 Tohoku earthquake and tsunami, citizens of the affected areas used Twitter to communicate their uncertain situation while users in other areas informed their followers via Twitter that they were safe (Acar & Muraki, 2011). By analyzing Twitter usage with "Tweak the Tweet" translators, the concept of "digital volunteers" converging to form strongly intertwined networks was discovered during the Haiti earthquake in 2010 (Starbird & Palen, 2011). Digital volunteers relay, amplify, synthesize and structure information in emergency situations (Starbird, 2013). Additionally, they perform tasks, which are usually not executed by official emergency services, for instance, the recovery of lost animals during hurricane Sandy in 2012 (White, Palen, & Anderson, 2014). Another function of social media allows users to offer support in crisis situations by expressing solidarity as in the 2011 Egyptian uprising (Starbird & Palen, 2012) and giving emotional encouragement as in the 2010 Great East Japan Earthquake (Wilensky, 2014). During the 2011 Super Tornado Outbreak (Reuter et al., 2013), those affected by the tornados retweeted warnings and crisis tracking activities during the preparedness and response phases of the event. Also, virtual self-help communities started their relief operations in the recovery phase along with a growing number of external source links. But not only Twitter is used in emergencies: In the 2010 Bornholm blizzard, the use of two Facebook groups indicates that self-selection into groups generates various opinions (Birkbak, 2012). Goolsby (2010) concentrates on ad-hoc crisis communities using social media to create community crisis maps. Until now, seven different crisis-mapping practices in OpenStreetMap have been identified (Kogan, Anderson, Palen, Anderson, & Soden, 2016).

If there is uncertainty caused by extra information and misinformation because of chaotic "unorganized" online behavior of the volunteers, "there will be a larger amount of collaboration on the platform" (Valecha, Oh, & Rao, 2013). Possible ways to improve the organization of online volunteers include cross-platform moderators (Reuter et al., 2015a) or the installation of public displays for volunteer coordination (Ludwig et al., 2017). Even though Purohit et al. (2014) propose a system designed to identify seekers and suppliers of information and resources in social media communities to encourage crisis coordination, many challenges remain. Cobb et al. (2014) suggest connecting different tools and tasks, coordinating and integrating voluntary activities, and giving volunteers the opportunity to share their activities so that spontaneous and less experienced volunteers may learn something new. Furthermore, Kaufhold and Reuter (2014) determine ways to ease procedures of moderation and independent work, to encourage digital and on-site volunteers in providing clarification and representation of important content, to support feedback as well as updates in interaction relationships and to include technologies and interaction types.

4.2. From authorities to citizens (A2C) – crisis communication

Today and increasingly in the future, authorities include social media into their crisis communication efforts to disseminate information on how to behave during emergencies and how to prevent accidents or emergencies (Reuter, Ludwig, Kaufhold, & Spielhofer, 2016b). The 2009 case study of Public Information Officers (PIO) of the Los Angeles Fire Department emphasizes the significance of the information evangelist, who supports the use of new forms of media and technology to attain an efficient organizational application of social media (Latonero & Shklovski, 2011). According to Hughes and Palen (2012), members of the public "have a changed relationship to the institution of emergency response" through the authorities' use of social media. Authorities also correct misinformation caused by the "emerging risks of the chaotic use of social media" (Kaewkitipong, Chen, & Ractham, 2012), as shown in a study about the

Thailand flooding disaster in 2011. Additionally, a study investigating crisis communication in the context of the Fukushima Daiichi nuclear disaster demonstrates that crisis communication through social media can be more effective than traditional media (Utz, Schultz, & Glocka, 2013). In crisis communication, instrumental and public-including expressive communication approaches through Twitter have been implemented by police units in the 2011 London riots (Denef et al., 2013). Another study on 2012 hurricane Sandy demonstrates that communication in fire and police departments and across media types differs (Hughes et al., 2014) and therefore, the study recommends new features and tools "to better track, respond to, and document public information." Veil et al. (2011) offer recommendations for practitioners, best practices and examples of social media tools. Time-series analyses expose that relevant information becomes less dominant as the crisis moves from the prodromal to acute phase and that information regarding individual remedial behaviors decreases analogously (Spence, Lachlan, Lin, & Del Greco, 2015).

Authorities must deal with many hurdles concerning the use of social media. An exploratory study investigates the collaboration among humanitarian aid organizations and Volunteer and Technical Communities (V&TCs), classifying the latter into software platform development communities, mapping collaborations, expert networks, and data aggregators (Van Gorp, 2014). In this study, six barriers of collaboration with aid organizations are identified: the management of volunteers, different levels of engagement, the level of commitment by V&TCs, diverse ways of working, limited resources and the aid for organizations' limited knowledge about the V&TCs' expertise. Plotnick and Hiltz (2016) demonstrate how county-level US emergency managers use social media, review barriers to efficient social media use, and offer suggestions to improve use. This study finds that for both disseminating information (A2C) and collecting information (C2A), lack of sufficient staff is the most important barrier. The lack of guidance/policy documents is the second highest rated barrier to dissemination via social media. The study also found that the lack of skills and the training that could improve these skills is also important.

4.3. From citizens to authorities (C2A) – use of citizen-generated content

The use of citizen-generated content by authorities is also important because there is great potential to analyze problematic situations based on diverse citizen-generated content, including text, pictures, and videos taken with mobile phones. For example, emergency services can use data from social media to calculate statistical measures, e.g., estimate citizen alertness using data mining (Johansson, Brynielsson, Quijano, & Narganes Quijano, 2012). The high number of social media posts might improve the accuracy of the statistical measures in this case. However, citizen-generated information is often unreliable and a significant obstacle in investigating such possibilities (Mendoza, Poblete, & Castillo, 2010). One way to improve the reliability of this information is through crowdsourcing strategies (Reuter et al., 2012). For instance, based on prior research of the crowds' self-correcting capabilities, Arif et al. (Arif et al., 2017) propose a model for twitter rumor correction and emphasize the locus of responsibility, corrective objective, and perceptions of the audience to choose the correcting action. Hughes and Palen (2014) identify the challenges of verification, liability, credibility, information overload, and allocation of resources in a broad literature review about the integration of social media content. Moreover, a study on the 2010 Haiti earthquake demonstrates possibilities of social media for disaster relief with respect to donations toward the Red Cross (Gao, Barbier, & Goolsby, 2011). Akhgar et al. (2013) explain how security organizations and public safety are increasingly aware of social media's added value proposition in times of crisis. Meanwhile, another study recommends that volunteer groups in emergencies in the future must mature and improve according to these enhanced opportunities, so that "professional responders will begin to rely on data and products produced by digital volunteers" (Hughes & Tapia, 2015).

Many methods and applications in crisis informatics research include citizen-generated content and encourage authorities to process social media content. To evaluate situated crowdsourcing mechanisms, Ludwig et al. (2017) execute a public display application with a reliable communication infrastructure. Furthermore, Castillo (2016) collects methods (e.g., NLP, semantic technologies, data mining) to process social media messages *under time-critical limitations*. Various research studies seek to extract *situational awareness* from social media. For example, Vieweg et al. (2010) identify categories of information found on Twitter that could improve situational awareness. Pohl, Bouchachia, and Hellwagner (2015) show clustering approaches for sub-event detection on Flickr and YouTube to automate the processing of data in social media. Meanwhile, Sakkaki et al. (2010) offer an algorithm that integrates Twitter users as social sensors for real-time event detection concerning the Japanese earthquakes in 2009. Additionally, De Albuquerque, Herfort, Brenning, and Zipf (2015) prove that geographical approaches for quantitatively assessing social media messages might be helpful to enhance important content. Moi et al. (2015) suggest a system to process and investigate social media data, transforming the high volume of noisy data into a low volume of rich content that emergency personnel can use. To succeed, they categorize the steps of information gathering and data preparation, information mining, data enrichment, alert detection, information visualization, semantic data modeling with ontologies, and information quality assessment.

To examine challenges and future research directions involving techniques for data characterization, clustering, acquisition, classification, preparation, event detection and tracking, extraction, summarization, and semantic technologies, Imran et al. (2015) provide a comprehensive overview of managing social media messages. Another study by Pohl (2013) concentrates on tools and existing frameworks developed in the context of non-crisis related (e.g., Twitinfo) and crisis related (e.g., Twitcident or "Tweak the Tweet") research work to investigate social media or to integrate new features into the social media usage for crisis management. Starbird and Stamberger (2010) suggest using structured crisis-specific

Twitter hashtags to ease machine parsing, processing, and redistribution for the proposed micro syntax "Tweak the Tweet" and to make information, which was generated during emergencies, more useful. In this comparison, they detect that there are systems for diverse applications, reflecting one or various social media platforms for monitoring, especially developed for crisis management, and executing different kinds of analysis: event-detection, sentiment analysis, and monitoring. Nevertheless, other studies have demonstrated simultaneously that not all responders use such data during disasters, as there are complications with obtaining and filtering large amounts of data in emergencies (Hughes & Palen, 2012; Reuter, Amelunxen, & Moi, 2016a). The Plotnick and Hiltz (2016) study of county-level U.S. emergency managers states that after lack of staff, the most important barriers to collecting information (C2A) are trustworthiness of the data, and information overload issues, which points to the need for appropriate software support to deal with these system-related issues.

4.4. From authorities to authorities (A2A) – organizational crisis management

Social media such as Twitter or Facebook often do not encourage the inter- and intra-organizational cooperation (A2A) of authorities. Nonetheless, social media may help to enhance informal processes and inter-organizational awareness. White, Plotnick, Kushma, Hiltz, and Turoff (2009) investigate the capabilities of online social networks with emergency management students and find that the most popular functions were the distribution of information, communication, and networking. Additionally, it is demonstrated that, for instance, information integrity, user identification, privacy, and technology reliability are potential issues with those systems. Experiences show that inter-organizational social networks for authorities could create potential value (Pipek, Reuter, Ley, Ludwig, & Wiedenhoefer, 2013; Reuter, 2014). Authorities can also use social media for internal communication. A study on 2010 Haiti Earthquake shows how social media technologies such as wikis and collaborative workspaces can be employed as knowledge sharing systems (Yates & Paquette, 2011).

4.5. Summary of usage patterns

Looking at the different types of interaction, as defined by Reuter et al. (2012), we summarize what can be learned about the four usage patterns from the crisis informatics literature:

Citizens to Citizens (C2C): Most people use social media during crises to communicate with other citizens. In this context, social media serve self-coordination purposes. Additionally, they are mainly used among citizens for information sharing and obtaining, especially information about people's well-being and the status of uncertain situations, and for providing or receiving emotional support. However, there are still some challenges to simplify social media use during crises and increase their reliability.

Authorities to Citizens (A2C): Social media are increasingly used by authorities for their crisis communication with the public. In this context, a variety of studies investigate how social media are actually used and how they might be used and demonstrate the importance of social media for disseminating information to the public. Nevertheless, barriers, such as a lack of staff and reliability are still challenges for efficient social media use by authorities.

Citizens to Authorities (C2A): The integration of citizen-generated content is important for authorities. Through data mining, important information can be gathered from the mass number of posts on the Internet and strategies such as crowdsourcing can counteract the unreliability of such information. Research in this area concentrates on methods and applications that promote both an efficient collection and use of social media data.

Authorities to Authorities (A2A): Social media can be used in inter- and intra-organizational cooperation for distributing information, communicating, networking, and sharing knowledge.

5. Discussion and conclusion

Social media continue to evolve, and so does their use in emergency and crisis events. Since the first recorded case of disaster relief with social media in 2001, the use of social media before, during, and after crisis events has become more and more pervasive. Emergency and disaster management as well as defense and security management continue to converge. In the field of crisis informatics, studies have investigated various cases, methods, practices, tools, and users in crises, disasters, and emergencies of all types and sizes. In this final section, we summarize the findings of our evaluation and analysis of crisis informatics literature and explore the future of this research.

Other review studies have systematically analyzed social media use across multiple emergencies or technologies. For example, Olteanu, Vieweg, and Castillo (2015) report on the average prevalence of various information types, sources and their temporal distribution across a variety of crisis situations. Eismann, Posegga, and Fischbach (2016) executed a systematic literature study on collective behavior identifying seven key findings concerning the event, impact, social units, and response. From a technological perspective, Imran et al. (2015) surveyed "the state of the art regarding computational methods to process social media messages and highlight both their contributions and shortcomings". Likewise, Castillo (2016) highlights computational methods "focusing on methods that are commonly used for processing social media messages under time-critical constraints". This paper aims to contribute by examining case studies and identifying use patterns that describe the interactions among authorities and citizens.

Section 2 of this article surveys studies focusing on the use of social media during many of the most significant emergency events to happen world-wide since 2001. Initial research focused on events that took place in the USA, but more recently there have been a growing number of studies based on crisis events in other countries. This increasing diversity has enabled more comparative and systematic analysis across diverse types of emergency contexts. However, the

crisis informatics literature continues to heavily emphasize the Twitter social media platform, mostly due to the ease of data collection and accessibility that the platform affords.

Section 3 provides an overview of the different types of research that can be found in the crisis informatics literature. Much of this research is empirical, where researchers collect social media data or conduct interviews with social media users to better understand the behaviors that social media support in crisis management. Other research seeks to address the task of collecting, processing, and making sense of large amounts of social media data. Still other research involves designing, building, and testing systems that help users use social media more effectively in times of crisis. The final type of research discussed in this section takes a broader view of the crisis informatics field by summarizing and pulling together research across the field to address larger problems and research questions.

In Section 4, the analysis attaches importance to various *use patterns*, involving the communication among citizens (C2C), with concepts of self-coordination and help, emergent groups, and (digital) volunteers; the communication from authorities to citizens (A2C), involving concepts of crisis communication; from citizens to authorities (C2A), involving concepts like big data- or social media analysis, crowdsourcing, and crowd tasking; and among authorities (A2A), involving inter-organizational social networks.

Despite an increasingly broad scope of crisis informatics literature, there remain many areas open for future practice and research:

Bias of English Twitter studies: As mentioned above (see Section 2) we observed a strong bias toward studies that examine Twitter (overestimating its importance in crisis management?) as well as datasets in the English language, which limit the diversity of research. Future research should look more broadly at all the variations of social media as well as different languages to represent a more complete picture of how social media is used in crisis around the world.

Self-coordination and help (C2C) among citizens are assumed to be important, but some studies have identified chaos as a consequence of this interaction. Researchers are seeking ways to bring order to this perceived chaos. While flexibility is also necessary, the automatic cross-media recommending of relevant posts pursuant to crises dynamics of interest (Kaufhold & Reuter, 2016) or the adjusting of needs and offers (Purohit et al., 2014) could help to structure communication. The granularity of citizen activities is also essential to define appropriate work practices and organization. For instance, what role should groups of citizens (e.g., soccer clubs or individual citizens) play in crisis management? To ease adaption and appropriation of existing tools amongst citizens and, long-term, to enhance disaster preparedness, the visibility of various practices that prove their functionality is important.

Crisis communication (A2C) is still a challenge. Pursuant to particular studies, many citizens anticipate that authorities will respond to their messages within one hour (Reuter & Spielhofer, 2017). Spokespeople must conform to a new role, which contains more dynamics in comparison to pre-social media times. To meet these expectations, spokespeople must take the time to carefully word their posts which is not conducive to responding, as expected by the public, immediately. Thus, types of communication, such as instrumental or public-including expressive communication approaches (Denef et al., 2013), must be further investigated to recommend crisis communication strategies that fit the needs of different authorities.

Different algorithmic approaches have been applied to study and *include citizen-generated content* (C2A) from social media (Imran et al., 2015). On the one hand, they are supposed to identify or predict critical events and to convert the high volume of big and noisy data, which cannot be managed by emergency managers in a short time before or during large-scale emergencies, to a low volume of rich and thick content (Moi et al., 2015). On the contrary, algorithms are supposed to identify underlying patterns (e.g., mood or geospatial correlations) applying statistical approaches or visual analytics (Brynielsson, Johansson, Jonsson, & Westling, 2014; Fuchs, Andrienko, Andrienko, Bothe, & Stange, 2013). Fake news and social bots complicate these efforts, but one should take into account the various granularities of disasters, such as large-scale incidents and smaller emergencies, with suitable algorithms and thresholds. Emergency managers are sometimes not convinced of the quality of citizen-generated content and social media (Hughes & Tapia, 2015; Reuter et al., 2016b). Still, they might trust in the quality of algorithms as an additional filtering layer, e.g., by offering a degree of customizability and transparency (white-box approach). In addition to that, research investigated crowd-sensing approaches to attaching the authorities' importance to citizens' activities (Ludwig, Reuter, Siebigteroth, & Pipek, 2015a; Sakaki, Okazaki, & Matsuo, 2010).

Referring to *inter- and intra-organizational crisis management* (A2A), social media serve as help for the coordination of crisis communication and a more informal networking among employees and authorities. In this context, it is possible that social media structures encourage the expansion of collaborative ICT or inform encapsulated social networks. As the usage group is limited and controlled, the latter benefit from trust.

Considering the HCI discourse, *ubiquitous computing* or the ubiquity of social media, related (mobile) applications and devices, such as smartphones, wearables and Internet of things platforms (IoT), constitute an increasing impact on the interaction between authorities and citizens. In a *hyperconnectivity* environment (Harper, Rodden, Rogers, & Sellen, 2008), social media increases the authorities' reach for crisis communication and organizational promotion (A2C) (Reuter et al., 2016b), but also allows the integration of citizen-generated *mixed media* content (C2A) such as images, sounds, voice, and videos to increase situational awareness. The increasing availability of high-bandwidth infrastructures promotes the integration of real-time information, e.g., via live streams. Given the limited resources in personnel and time on the one hand, and the increased HCI rate, referred to as *high-bandwidth interaction* in HCI, on the other hand, algorithms and customizable interfaces intend to support the processing of big social data. In the future, augmented reality and speech recognition as well as

social bots, acting as autonomous technological entities, promise to support authorities in the structured dissemination, mediation, or retrieval of information. One example includes the automatic matching of offers and needs in social media (Purohit et al., 2014; Reuter et al., 2015a) with the help of bots that provide automatic posts to highlight possible matches. Moreover, if in compliance with organizational policies, instant messengers allow authorities to enhance intra- and inter-organizational communication (A2A). The increasing availability and distribution of mobile devices and related social media apps facilitates information retrieval, mobilization and autonomous self-organization among citizens (C2C). While institutions develop specific disaster-purpose apps, e.g., FEMA or KATWARN, social media providers are also integrating emergency-specific functionality, such as Facebook Safety Check or Twitter Alerts, into their general-purpose applications (Reuter, Kaufhold, Leopold, & Knipp, 2017). In conclusion, interactions among authorities and citizens as well as interaction design and technology development have been and will continue to be challenged through the rapidly changing landscape of social media platforms, types, and their API's (Reuter & Scholl, 2014).

Notes

1. https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/.
2. This table extends an earlier version (Reuter & Kaufhold, 2018).

Acknowledgments

Parts of this article are based on a previous summary of crisis informatics research (Reuter & Kaufhold, 2018). The research group *KontiKat* was funded by the German Federal Ministry of Education and Research (BMBF) (no. 13N14351).

ORCID

Christian Reuter http://orcid.org/0000-0003-1920-038X

References

Acar, A., & Muraki, Y. (2011). Twitter for crisis communication: Lessons learned from Japan's tsunami disaster. *International Journal of Web Based Communities*, *7*(3), 392–402.

Akhgar, B., Fortune, D., Hayes, R. E., Guerra, B., & Manso, M. (2013). Social media in crisis events: Open networks and collaboration supporting disaster response and recovery. In *2013 IEEE International Conference on Technologies for Homeland Security (HST)* (pp. 760–765). IEEE. doi:10.1109/THS.2013.6699099

American Red Cross. (2012). More Americans using mobile apps in emergencies. Retrieved from http://www.redcross.org/news/press-release/More-Americans-Using-Mobile-Apps-in-Emergencies

An, J., Kwak, H., Mejova, Y., & Oger, D. (2016). Are you Charlie or Ahmed? Cultural pluralism in Charlie Hebdo response on Twitter. In *International AAAI Conference on Web and Social Media* pp. 1–10.

Anderson, K. M., & Schram, A. (2011). Design and implementation of a data analytics infrastructure in support of crisis informatics research: NIER track. *2011 33rd International Conference on Software Engineering (ICSE)*, 844–847. doi:10.1145/1985793.1985920

Andrews, C., Fichet, E., Ding, Y., Spiro, E. S., & Starbird, K. (2016). Keeping up with the tweet-dashians: The impact of "Official" accounts on online rumoring. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16)* (pp. 452–465). New York, USA: ACM Press. doi:10.1145/2818048.2819986

Arif, A., Robinson, J. J., Stanek, S. A., Fichet, E. S., Townsend, P., Worku, Z., & Starbird, K. (2017). A closer look at the self-correcting crowd: Examining corrections in online rumors. In *Proceedings of the Conference on Computer-Supported Cooperative Work & Social Computing (CSCW)* (pp. 155–168). New York, NY, USA: ACM. doi:10.1145/2998181.2998294

Arif, A., Shanahan, K., Chou, F.-J., Dosouto, Y., Starbird, K., & Spiro, E. S. (2016). How information snowballs: Exploring the role of exposure in online rumor propagation. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (pp. 466–467). New York, USA: ACM Press. doi:10.1145/2818048.2819964

Birkbak, A. (2012). Crystallizations in the Blizzard: Contrasting informal emergency collaboration in facebook groups. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI)* (pp. 428–437). Copenhagen, Denmark: ACM.

Brocke, J., Simons, A., Riemer, K., Niehaves, B., & Plattfaut, R. (2015). Standing on the shoulders of giants: Challenges and recommendations of literature search in information systems research. *Communications of the AIS*, *37*(1), 205–224. Retrieved from http://aisel.aisnet.org/cgi/viewcontent.cgi?article=3874&context=cais.

Bruns, A., & Burgess, J. E. (2012). Local and global responses to disaster: #eqnz and the Christchurch earthquake. In *Proceedings of the Disaster and Emergency Management Conference* (pp. 86–103). Brisbane, QLD: AST Management Pty Ltd.

Brynielsson, J., Johansson, F., Jonsson, C., & Westling, A. (2014). Emotion classification of social media posts for estimating people's reactions to communicated alert messages during crises. *Security Informatics*, *3*(1), 7.

Burnap, P., Williams, M. L., Sloan, L., Rana, O., Housley, W., Edwards, A., … Voss, A. (2014). Tweeting the terror: Modelling the social media reaction to the Woolwich terrorist attack. *Social Network Analysis and Mining*, *4*(1), 1–14. 10.1007/s13278-014-0206-4

Cameron, M. A., Power, R., Robinson, B., & Yin, J. (2012). Emergency situation awareness from twitter for crisis management. In *Proceedings of the 21st international conference companion on World Wide Web* (pp. 695–698). New York, USA: ACM Press. 10.1145/2187980.2188183

Caragea, C., Mcneese, N., Jaiswal, A., Traylor, G., Kim, H., Mitra, P., … Yen, J. (2011). Classifying text messages for the Haiti earthquake. *Proceedings of the 8th International ISCRAM Conference*, (May), 1–10. https://doi.org/10.1.1.370.6804

Castillo, C. (2016). *Big crisis data - Social media in disasters and time-critical situations*. New York, NY, USA: Cambridge University Press.

Castillo, C., Mendoza, M., & Poblete, B. (2011). Information credibility on twitter. In *Proceedings of the 20th international conference on World wide web* (pp. 675–684). New York, USA: ACM Press. 10.1145/1963405.1963500

Chaturvedi, A., Simha, A., & Wang, Z. (2015). ICT infrastructure and social media tools usage in disaster/crisis management. In *2015 Regional Conference of the International Telecommunications Society (ITS), Los Angeles, CA, 25–28 October, 2015*. Los Angeles, CA.

Chauhan, A., & Hughes, A. L. (2017). Providing online crisis information: An analysis of official sources during the 2014 Carlton complex wildfire. In *Proceedings of the 35th International Conference on Human Factors in Computing Systems (CHI 2017)*. doi:10.1145/3025453.3025627

Cobb, C., McCarthy, T., Perkins, A., Bharadwaj, A., Comis, J., Do, B., & Starbird, K. (2014). Designing for the Deluge: understanding & supporting the distributed, collaborative work of crisis volunteers. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)* (pp. 888–899). Baltimore, USA. doi:10.1145/2531602.2531712

Cross, C. R. (2012). *Social media during emergencies*. Retrieved from http://www.redcross.ca/cmslib/general/pub_social_media_in_emergencies_survey_oct2012_en.pdf

De Albuquerque, J. P., Herfort, B., Brenning, A., & Zipf, A. (2015). A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management. *International Journal of Geographical Information Science*, *29*(4), 667–689. 10.1080/13658816.2014.996567

Denef, S., Bayerl, P. S., & Kaptein, N. (2013). Social media and the police—Tweeting practices of British police forces during the August 2011 Riots. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 3471–3480). Paris, France: ACM Press. 10.1145/2470654.2466477

Eismann, K., Posegga, O., & Fischbach, K. (2016). Collective behaviour, social media, and disasters: A systematic literature review. In *European Conference on Information Systems (ECIS)*.

Endsley, T., Wu, Y., Reep, J., Eep, J., & Reep, J. (2014). The source of the story: Evaluating the credibility of crisis information sources. In S. R. Hiltz, M. S. Pfaff, L. Plotnick, & P. C. Shih (Eds.), In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (Vol. 1, pp. 158–162). University Park, PA, USA: ISCRAM.

Fichet, E., Robinson, J., & Starbird, K. (2015). Eyes on the ground: Emerging practices in periscope use during crisis events. In *Proceedings of the 13th International ISCRAM Conference*.

Flizikowski, A., Hołubowicz, W., Stachowicz, A., Hokkanen, L., & Delavallade, T. (2014). Social media in crisis management – The iSAR + project survey. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 707–711).

Fuchs, G., Andrienko, N., Andrienko, G., Bothe, S., & Stange, H. (2013). Tracing the German Centennial flood in the stream of tweets: First lessons learned. In P. Dieter & V. Agnès (Eds.), *SIGSPATIAL International Workshop on Crowdsourced and Volunteered Geographic Information* (pp. 2–10). Orlando, USA.

Fung, I. C.-H., Tse, Z. T. H., Cheung, C.-N., Miu, A. S., & Fu, K.-W. (2014). Ebola and the social media. *The Lancet*, *384*(9961), 2207. 10.1016/S0140-6736(14)62418-1

Gao, H., Barbier, G., & Goolsby, R. (2011). Harnessing the crowdsourcing power of social media for disaster relief. *IEEE Intelligent Systems*, *26*(3), 10–14.

Goolsby, R. (2010). Social media as crisis platform. *ACM Transactions on Intelligent Systems and Technology*, *1*(1), 1–11. 10.1145/1858948.1858955

Hagar, C. (2007). The information needs of farmers and use of ICTs. *In* B. Nerlich & M. Doring (Eds.), *From Mayhem to meaning: Assessing the social a nd cultural impact of the 2001 foot and mouth outbreak in the UK*. Manchester, United Kingdom: Manchester University Press.

Harper, R., Rodden, T., Rogers, Y., & Sellen, A. (2008). *Being human: Human-Computer interaction in the year 2020*. Cambridge, England: Microsoft Research Ltd.

Harrald, J. R., Egan, D. M., & Jefferson, T. (2002). Web enabled disaster and crisis response: What have we learned from the September 11 th. In *Proceedings of the Bled eConference* (pp. 69–83). Retrieved from https://domino.fov.uni-mb.si/proceedings.nsf/proceedings/d3a6817c6cc6c4b5c1256e9f003bb2bd/$file/harrald.pdf

Helsloot, I., & Groenendaal, J. (2013). Twitter: An underutilized potential during sudden crises? *Journal of Contingencies and Crisis Management*, *21*(3), 178–183. 10.1111/1468-5973.12023

Helsloot, I., & Ruitenberg, A. (2004). Citizen response to disasters: A survey of literature and some practical implications. *Journal of Contingencies and Crisis Management*, *12*(3), 98–111.

Heverin, T., & Zach, L. (2010). Microblogging for crisis communication: Examination of twitter use in response to a 2009 violent crisis in the Seattle-Tacoma, Washington area. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–5). Seattle, USA.

Hiltz, S. R., Diaz, P., & Mark, G. (2011). Introduction: Social media and collaborative systems for crisis management. *ACM Transactions on Computer-Human Interaction (Tochi)*, *18*(4), 1–6.

Hiltz, S. R., Kushma, J., & Plotnick, L. (2014). Use of social media by US public sector emergency managers: Barriers and wish lists. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 600–609). University Park, PA, USA. Retrieved from http://www.iscramlive.org/ISCRAM2014/papers/p90.pdf

Hughes, A. L. (2014). Participatory design for the social media needs of emergency public information officers. In *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM)*. University Park, PA, USA. Retrieved from http://www.iscramlive.org/ISCRAM2014/papers/p90.pdf

Hughes, A. L., & Chauhan, A. (2015). Online media as a means to affect public trust in emergency responders. In *Proceedings of the 2014 Information Systems for Crisis Response and Management Conference (ISCRAM 2015)*. Retrieved from http://iscram2015.uia.no/?p=2020

Hughes, A. L., & Palen, L. (2012). The evolving role of the public information officer: An examination of social media in emergency management. *Journal of Homeland Security and Emergency Management (JHSEM)*, *9*(1). Article 22 10.1515/1547-7355.1976.

Hughes, A. L., & Palen, L. (2009). Twitter adoption and use in mass convergence and emergency events. In J. Landgren & S. Jul (Eds.), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*. Gothenburg, Sweden.

Hughes, A. L., & Palen, L. (2014). *Social media in emergency management: Academic perspective*. In J. E. Trainor & T. Subbio, Eds., Critical Issues in Disaster Science and Management: A Dialogue Between Scientists and Emergency Managers. FEMA in Higher Education Program.

Hughes, A. L., Palen, L., Sutton, J., Liu, S. B., & Vieweg, S. (2008). "Site-Seeing" in disaster: An examination of on-line social convergence. In *In Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2008)*. Washington D.C., USA. Retrieved from http://idl.iscram.org/files/hughes/2008/605_Hughes_etal2008.pdf

Hughes, A. L., & Shah, R. (2016). Designing an application for social media needs in emergency public information work. In *In Proceedings of the 19th International Conference on Supporting Group Work* (pp. 399–408). New York, USA: ACM Press. doi:10.1145/2957276.2957307

Hughes, A. L., St. Denis, L. A., Palen, L., & Anderson, K. M. (2014). Online public communications by police & fire services during the 2012 Hurricane Sandy. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 1505–1514). Toronto, Canada: ACM Press. 10.1145/2556288.2557227

Hughes, A. L., Starbird, K., Leavitt, A., Keegan, B., & Semaan, B. (2016). Information movement across social media platforms during crisis events. *CHI'16 Extended Abstracts*, *1–5*. doi:10.1145/2851581.2856500

Hughes, A. L., & Tapia, A. H. (2015). social media in crisis: when professional responders meet digital volunteers. *Journal of Homeland Security and Emergency Management (JHSEM)*, *12*(3), 679–706.

IFRC. (2015). *World Disaster Report 2015: Focus on local actors, the key to humanitarian effectiveness*. doi:10.1017/CBO9781107415324.004

Imran, M., Castillo, C., Diaz, F., & Vieweg, S. (2015). Processing social media messages in mass emergency: a survey. *ACM Computing Surveys*, *47*(4), 1–38. 10.1145/2771588

Imran, M., Castillo, C., Lucas, J., Meier, P., & Vieweg, S. (2014). AIDR: Artificial intelligence for disaster response. In *Proceedings of the Companion Publication of the 23rd International Conference on World Wide Web Companion* (pp. 159–162). Republic and Canton of Geneva, Switzerland: International World Wide Web Conferences Steering Committee. doi:10.1145/2567948.2577034

Jennex, M. E. (2012). Social media – Truly viable for crisis response? In L. Rothkrantz, J. Ristvej, & Z. Franco (Eds.), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–5). Vancouver, Canada.

Johansson, F., Brynielsson, J., Quijano, M. N., & Narganes Quijano, M. (2012). Estimating citizen alertness in crises using social media monitoring and analysis. *2012 European Intelligence and Security Informatics Conference*, 189–196. doi:10.1109/EISIC.2012.23

Kaewkitipong, L., Chen, C., & Ractham, P. (2012). Lessons learned from the use of social media in combating a crisis: A case study of 2011 Thailand flooding disaster. In *Proceedings of the International Conference on Information Systems (ICIS)* (pp. 1–17).Orlando, USA.

Kaufhold, M.-A., & Reuter, C. (2014). Vernetzte Selbsthilfe in Sozialen Medien am Beispiel des Hochwassers 2013/Linked Self-Help in Social

Media using the example of the Floods 2013 in Germany. *I-Com - Zeitschrift Für Interaktive Und Kooperative Medien*, *13*(1), 20–28.

Kaufhold, M.-A., & Reuter, C. (2016). The self-organization of digital volunteers across social media: The case of the 2013 European Floods in Germany. *Journal of Homeland Security and Emergency Management (JHSEM)*, *13*(1), 137–166.

Kogan, M., Anderson, J., Palen, L., Anderson, K. M., & Soden, R. (2016). Finding the way to OSM mapping practices: Bounding large crisis datasets for qualitative investigation. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16* (pp. 2783–2795). doi:10.1145/2858036.2858371

Kristensen, M., Kyng, M., & Palen, L. (2006). Participatory design in emergency medical service: Designing for future practice. In *In Proceedings of the ACM 2006 Conference on Human Factors in Computing Systems (CHI 2006)* (pp. 161–170). New York, USA: ACM Press.

Kuttschreuter, M., Rutsaert, P., Hilverda, F., Regan, Á., Barnett, J., & Verbeke, W. (2014). Seeking information about food-related risks: The contribution of social media. *Food Quality and Preference*, *37*, 10–18.

Latonero, M., & Shklovski, I. (2011). Emergency management, twitter, and social media evangelism. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)*, *3*(4), 1–16.

Liu, S. B. (2014). Crisis crowdsourcing framework: Designing strategic configurations of crowdsourcing for the emergency management domain. *Computer Supported Cooperative Work (CSCW)*, *23*(4–6), 389–443.

Liu, S. B., Palen, L., & Sutton, J. (2008). In search of the bigger picture: The emergent role of on-line photo sharing in times of disaster. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*. Washington D.C., USA. Retrieved from http://idl.iscram.org/files/liu/2008/716_Liu_etal2008.pdf

Ludwig, T., Kotthaus, C., Reuter, C., Dongen, S., Van Pipek, V., Van Dongen, S., … Pipek, V. (2017). Situated crowdsourcing during disasters: Managing the tasks of spontaneous volunteers through public displays. *International Journal on Human-Computer Studies (IJHCS)*, *102*(C), 103–121. https://doi.org/j.ijhcs.2016.09.008

Ludwig, T., Reuter, C., Siebigteroth, T., & Pipek, V. (2015). CrowdMonitor: Mobile Crowd Sensing for Assessing Physical and Digital Activities of Citizens during Emergencies. In Proceedings of the Conference on Human Factors in Computing Systems (CHI) (pp. 4083–4092). Seoul, Korea: ACM Press. Retrieved from http://www.cscw.uni-siegen.de/publikationen/dokumente/2015/2015_ludwigreutersiebigterothpipek_crowdmonitor_chi.pdf

Ludwig, T., Reuter, C., Siebigteroth, T., & Pipek, V. (2015a). CrowdMonitor: Mobile crowd sensing for assessing physical and digital activities of citizens during emergencies. In B. Begole, K. Jinwoo, I. Kor, & W. Woontack (Eds.), *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 4083–4092). New York, USA: ACM Press. Retrieved from https://doi.org/Emergencies.

Marcus, A., Bernstein, M., Badar, O., Karger, D. R., Madden, S., & Miller, R. C. (2011). Twitinfo: Aggregating and visualizing microblogs for event exploration. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 227–236). Vancouver, Canada.

McClendon, S., & Robinson, A. C. (2012). Leveraging geospatially-oriented social media communications in disaster response. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*. Vancouver, Canada.

Medina, R. Z., & Diaz, J. C. L. (2016). Social media use in crisis communication management: An opportunity for local communities? In M. Z. Sobaci (Ed.), *Social Media and Local Governments* (pp. pp. 321–335). Cham, Switzerland: Springer International Publishing. doi:10.1007/978-3-319-17722-9-17

Mendoza, M., Poblete, B., & Castillo, C. (2010). Twitter Under Crisis: Can we trust what we RT ? In *Proceedings of the First Workshop on Social Media Analytics (SOMA)* (pp. 71–79). New York, NY, USA: ACM Press.

Moi, M., Friberg, T., Marterer, R., Reuter, C., Ludwig, T., Markham, D., … Muddiman, A. (2015). Strategy for processing and analyzing social media data streams in emergencies. In *Proceedings of the International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)*. Brest, France.

Muralidharan, S., Dillistone, K., & Shin, J.-H. (2011). The Gulf Coast oil spill: Extending the theory of image restoration discourse to the realm of social media and beyond petroleum. *Public Relations Review*, *37*(3), 226–232.

Murphy, T., & Jennex, M. E. (2006). Knowledge management, emergency response, and Hurricane Katrina. *International Journal of Intelligent Control Systems*, *11*(4), 199–208.

Nagy, A., Valley, C., & Stamberger, J. (2012). Crowd sentiment detection during disasters and crises. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–9). Vancouver, Canada.

Okolloh, O. (2009). Ushahidi, or "testimony": Web 2.0 tools for crowdsourcing crisis information. *Participatory Learning and Action*, *59*(1), 65–70.

Olteanu, A., Vieweg, S., & Castillo, C. (2015). What to expect when the unexpected happens: Social media communications across crises. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (pp. 994–1009). New York, NY, USA: ACM. doi:10.1145/2675133.2675242

Palen, L. (2008). Online social media in crisis events. *Educause Quarterly*, *3*, 76–78.

Palen, L., & Anderson, K. M. (2016). Crisis informatics: New data for extraordinary times. *Science*, *353*(6296), 224–225.

Palen, L., & Liu, S. B. (2007). Citizen communications in crisis: Anticipating a future of ICT-supported public participation. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 727–736). San Jose, USA: ACM Press. doi:10.1145/1240624.1240736

Palen, L., St. Denis, L. A., & Hughes, A. L. (2012). Trial by fire: The deployment of trusted digital volunteers in the 2011 shadow lake fire. In L. Rothkrantz, J. Ristvej, & Z. Franco (Eds.), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–10). Vancouver, Canada, Canada: ISCRAM.

Palen, L., Vieweg, S., Liu, S. B., & Hughes, A. L. (2009). Crisis in a networked world: Features of computer-mediated communication in the April 16, 2007, Virginia Tech event. *Social Science Computer Review*, *27*(4), 467–480.

Perng, S.-Y., Büscher, M., Wood, L., Halvorsrud, R., Stiso, M., Ramirez, L., & Al-Akkad, A. (2012). Peripheral response: Microblogging during the 22/7/2011 Norway attacks. In L. Rothkrantz, J. Ristvej, & Z. Franco (Eds), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*. Vancouver, Canada.

Pipek, V., Liu, S. B., & Kerne, A. (2014). Special Issue: Crisis Informatics and Collaboration. *Computer Supported Cooperative Work (CSCW*, *23*, 4–6.

Pipek, V., Reuter, C., Ley, B., Ludwig, T., & Wiedenhoefer, T. (2013). Sicherheitsarena – Ein Ansatz zur Verbesserung des Krisenmanagements durch Kooperation und Vernetzung. *Crisis Prevention – Fachmagazin Für Innere Sicherheit, Bevölkerungsschutz Und Katastrophenhilfe*, *3*(1), 58–59.

Plotnick, L., & Hiltz, S. R. (2016). Barriers to use of social media by emergency managers. *Journal of Homeland Security and Emergency Management (JHSEM)*, *13*(2). doi:10.1515/jhsem–2015–0068

Plotnick, L., Hiltz, S. R., Kushma, J. A., & Tapia, A. (2015). Red tape : Attitudes and issues related to use of social media by US County- level emergency managers. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*. Kristiansand, Norway: ISCRAM. Retrieved from http://idl.iscram.org/files/lindaplotnick/2015/1225_LindaPlotnick_etal2015.pdf

Pohl, D. (2013). Social media analysis for crisis management: A brief survey. Retrieved from http://stcsn.ieee.net/e-letter/vol-2-no-1/social-media-analysis-for-crisis-management-a-brief-survey

Pohl, D., Bouchachia, A., & Hellwagner, H. (2015). Social media for crisis management: Clustering approaches for sub-event detection. *Multimedia Tools and Applications*, *74*(11), 3901–3932.

Purohit, H., Hampton, A., Bhatt, S., Shalin, V. L., Sheth, A. P., & Flach, J. M. (2014). Identifying seekers and suppliers in social media

communities to support crisis coordination. *Computer Supported Cooperative Work: The Journal of Collaborative Computing (JCSCW)*, *23*(4–6), 513–545.

Qu, Y., Huang, C., Zhang, P., & Zhang, J. (2011). Microblogging after a major disaster in China: A case study of the 2010 Yushu Earthquake. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)* (pp. 25–34). Hangzhou, China: ACM.

Qu, Y., Wu, P. F., & Wang, X. (2009). Online community response to major disaster : A study of tianya forum in the 2008 Sichuan earthquake. In *Proceedings of the Hawaii International Conference on System Sciences (HICSS)* (pp. 1–11). Waikoloa, USA: IEEE Computer Society. doi:10.1109/HICSS.2009.330

Quarantelli, E. L. (1984). *Emergent citizen groups in disaster preparedness and recovery activities*. University of Delaware. Retrieved from http://udspace.udel.edu/handle/19716/1206

Quarantelli, E. L. (1988). Disaster crisis management: A summary of research findings. *Journal of Management Studies*, *25*(4), 373–385. Retrieved from http://udspace.udel.edu/bitstream/handle/19716/487/PP113.pdf.

Quarantelli, E. L., & Dynes, R. R. (1977). Response to social crisis and disaster. *Annual Review of Sociology*, *3*(1), 23–49.

Reuter, C. (2014). *Emergent Collaboration Infrastructures: Technology Design for Inter-Organizational Crisis Management* (*Ph.D. Thesis*). Siegen, Germany: Springer Gabler. Retrieved from http://www.springer.com/springer+gabler/bwl/wirtschaftsinformatik/book/978-3-658-08585-8

Reuter, C., Amelunxen, C., & Moi, M. (2016a). Semi-automatic alerts and notifications for emergency services based on cross-platform social media data –evaluation of a prototype. In H. C. Mayr & M. Pinzger (Eds), *Informatik 2016: Von Menschen für Menschen* (pp. 1805–1818). Klagenfurt, Austria: GI-Edition-Lecture Notes in Informatics (LNI). Retrieved from http://subs.emis.de/LNI/Proceedings/Proceedings259/P-259.pdf#page=1806.

Reuter, C., Heger, O., & Pipek, V. (2013). Combining real and virtual volunteers through social media. In T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, & T. Müller (Eds.), In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 780–790). Baden-Baden, Germany.

Reuter, C., & Kaufhold, M.-A. (2018). Fifteen years of social media in emergencies: A retrospective review and future directions for crisis informatics. *Journal of Contingencies and Crisis Management (JCCM)*, *26*(1), 1–17.

Reuter, C., Kaufhold, M.-A., Leopold, I., & Knipp, H. (2017). Katwarn, NINA or FEMA? Multi-Method study on distribution, use and public views on crisis apps. In *European Conference on Information Systems (ECIS)* (pp. 2187–2201). Guimarães, Portugal. Retrieved from http://aisel.aisnet.org/ecis2017_rp/139/

Reuter, C., Ludwig, T., Kaufhold, M.-A., & Pipek, V. (2015a). XHELP: Design of a cross-platform social-media application to support volunteer moderators in disasters. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 4093–4102). Seoul, Korea: ACM Press. doi:10.1145/2702123.2702171

Reuter, C., Ludwig, T., Kaufhold, M.-A., & Spielhofer, T. (2016b). Emergency services attitudes towards social media: A quantitative and qualitative survey across Europe. *International Journal on Human-Computer Studies (IJHCS)*, *95*, 96–111. doi:10.1016/j.2016(03),005.

Reuter, C., Ludwig, T., Kotthaus, C., Kaufhold, M.-A., Von Radziewski, E., & Pipek, V. (2016c). Big data in a crisis? Creating social media datasets for emergency management research. *I-Com: Journal of Interactive Media*, *15*(3), 249–264.

Reuter, C., Marx, A., & Pipek, V. (2012). Crisis management 2.0: Towards a systematization of social software use in crisis situations. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)*, *4*(1), 1–16.

Reuter, C., & Mentler, T. (2018). Special issue on human-computer-interaction and social media in safety-critical systems. *Journal of Contingencies and Crisis Management (JCCM*, *26*, 1.

Reuter, C., Mentler, T., & Geisler, S. (2015b). Special issue on human computer interaction in critical systems I: Citizen and volunteers. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM*, *7*, 2.

Reuter, C., & Scholl, S. (2014). Technical limitations for designing applications for social media. In M. Koch, A. Butz, & J. Schlichter (Eds), *Mensch & Computer: Workshopband* (pp. 131–140). München, Germany, Germany: Oldenbourg-Verlag. Retrieved from https://www.wineme.uni-siegen.de/paper/2014/2014_reuterscholl_technicallimitationssocialmedia_muc.pdf.

Reuter, C., & Spielhofer, T. (2017). Towards social resilience: A quantitative and qualitative survey on citizens' perception of social media in emergencies in Europe. *Journal Technological Forecasting and Social Change (TFSC)*, *121*, 168–180.

Robinson, A., Savelyev, A., Pezanowski, S., & MacEachren, A. M. (2013). Understanding the utility of geospatial information in social media. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 918–922). Baden-Baden, Germany.

Sagar, V. C. (2016). As the water recedes: Sri Lanka Rebuilds. *RSIS Commentaries*, *141*.

Sakaki, T., Okazaki, M., & Matsuo, Y. (2010). Earthquake shakes twitter users: real-time event detection by social sensors. *WWW '10: Proceedings of the 19th International Conference on World Wide Web*, 851. doi:10.1145/1772690.1772777

Semaan, B., & Mark, G. (2012). "Facebooking" towards crisis recovery and beyond: Disruption as an opportunity. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work* (pp. 27–36). New York, USA. doi:10.1145/2145204.2145214

Shklovski, I., Palen, L., & Sutton, J. (2008). Finding community through information and communication technology during disaster events. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)*. San Diego, USA: ACM-Press.

Soden, R., & Palen, L. (2016). Infrastructure in the wild: What mapping in post-earthquake nepal reveals about infrastructural emergence. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2796–2807. doi:10.1145/2858036.2858545

Spence, P. R., Lachlan, K. A., Lin, X., & Del Greco, M. (2015). Variability in twitter content across the stages of a natural disaster: implications for crisis communication. *Communication Quarterly*, *63*(2), 171–186.

Stallings, R. A., & El Quarantelli, E. L. (1985). Emergent citizen groups and emergency management. *Public Administration Review*, *45* (Special Issue), 93–100.

Starbird, K. (2013). Delivering patients to sacré coeur: Collective intelligence in digital volunteer communities. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 801–810). Paris, France: ACM. Retrieved from http://dl.acm.org/citation.cfm?id=2470769

Starbird, K., Maddock, J., Orand, M., Achterman, P., & Mason, R. M. (2014). Rumors, false flags, and digital vigilantes: Misinformation on twitter after the 2013 Boston Marathon Bombing. In *iConference 2014*. Berlin, Germany. doi:10.9776/14308.

Starbird, K., & Palen, L. (2010). Pass it on?: Retweeting in mass emergency. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–10). Seattle, USA.

Starbird, K., & Palen, L. (2011). Voluntweeters: Self-organizing by digital volunteers in times of crisis. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 1071–1080). Vancouver, Canada: ACM-Press. https://doi.org/10.1145/1978942.1979102

Starbird, K., Palen, L., Hughes, A. L., & Vieweg, S. (2010). Chatter on the red: What hazards threat reveals about the social life of microblogged information. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)* (pp. 241–250). New York, USA: ACM Press. doi:10.1145/1718918.1718965

Starbird, K., & Palen, L. (2012). (How) will the revolution be retweeted?: Information diffusion and the 2011 Egyptian uprising. In S. E. Poltrock, C. Simone, J. Grudin, G. Mark, & J. Riedl (Eds.), In *Proceedings of the Conference on Computer Supported Cooperative*

Work (CSCW). Bellevue, WA, USA: ACM Press. Retrieved from http://dl.acm.org/citation.cfm?id=2145212

Starbird, K., & Stamberger, J. (2010). Tweak the tweet: Leveraging microblogging proliferation with a prescriptive syntax to support citizen reporting. In S. French, B. Tomaszewski, & C. Zobel (Eds), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)*. Seattle, USA.

Sutton, J., Palen, L., & Shklovski, I. (2008). Backchannels on the front lines: Emergent uses of social media in the 2007 Southern California Wildfires. *In* F. Friedrich & B. Van De Walle (Eds), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM) (pp. 624–632)*. USA: Washington D.C.

Sutton, J. (2010). Twittering tennessee: Distributed networks and collaboration following a technological disaster. In S. French, B. Tomaszewski, & C. Zobel (Eds.), In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (Vol. 1, pp. 1–10). Seattle, USA. https://doi.org/citeulike-article-id:9471083

Sutton, J., Spiro, E. S., Johnson, B., Fitzhugh, S. M., Greczek, M., & Butts, C. T. (2012). Connected communications: Network structures of official communications in a technological disaster. In *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2012)*. Vancouver, BC, Canada. Retrieved from http://www.iscramlive.org/ISCRAM2012/proceedings/208.pdf

Tapia, A. H., Moore, K. A., & Johnson, N. J. (2013). Beyond the Trustworthy tweet: A deeper understanding of microblogged data use by disaster response and humanitarian relief organizations. In *Proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM 2013)*. Retrieved from http://www.iscramlive.org/ISCRAM2013/files/121.pdf

Terpstra, T., De Vries, A., Stronkman, R., & Paradies, G. L. (2012). Towards a realtime Twitter analysis during crises for operational crisis management. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 1–9). Vancouver, Canada.

Twitter. (2014). TweetDeck. Retrieved July 23, 2014, from https://about.twitter.com/products/tweetdeck

Utz, S., Schultz, F., & Glocka, S. (2013). Crisis communication online: How medium, crisis type and emotions affected public reactions in the Fukushima Daiichi nuclear disaster. *Public Relations Review*, *39* (1), 40–46.

Valecha, R., Oh, O., & Rao, R. (2013). An exploration of collaboration over time in collective crisis response during the Haiti 2010 Earthquake. In R. Baskerville & M. Chau (Eds.), *Proceedings of the International Conference on Information Systems (ICIS)* (pp. 1–10). Milan, Italy: Association for Information Systems. Retrieved from http://aisel.aisnet.org/icis2013/proceedings/ResearchInProgress/96/

Van Gorp, A. F. (2014). Integration of volunteer and technical communities into the humanitarian aid sector: Barriers to collaboration. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 620–629).

Veil, S. R., Buehner, T., & Palenchar, M. J. (2011). A work-in-process literature review: Incorporating social media in risk and crisis communication. *Journal of Contingencies and Crisis Management*, *19*(2), 110–122.

Vieweg, S., Hughes, A. L., Starbird, K., & Palen, L. (2010). Microblogging during two natural hazards events: What twitter may contribute to situational awareness. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI)* (pp. 1079–1088). Atlanta, USA: ACM.

Wan, S., & Paris, C. (2015). Understanding Public Emotional Reactions on Twitter. In M. Cha, C. Mascolo, & C. Sandvig (Eds.), In *Proceedings of the Ninth International AAAI Conference on Web and Social Media* (pp. 715–716). AAAI Press.

White, C., & Plotnick, L. (2010). A framework to identify best practices: Social media and web 2.0 technologies in the emergency domain. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM*, *2*, 1.

White, C., Plotnick, L., Kushma, J., Hiltz, S. R., & Turoff, M. (2009). An online social network for emergency management. *International Journal of Emergency Management (IJEM)*, *6*(3/4), 369–382.

White, J., Palen, L., & Anderson, K. M. (2014). Digital mobilization in disaster response: The work & self - organization of on-line pet advocates in response to Hurricane Sandy. In S. R. Fussell, W. G. Lutters, M. R. Morris, & M. Reddy (Eds), *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)* (pp. pp. 866–876). Baltimore, USA: ACM.

White, J., & Palen, L. (2015). Expertise in the wired wild west. In D. Cosley, A. Forte, L. Ciolfi, & D. McDonald (Eds.), In *Proceedings of the ACM Conference on Computer-Supported-Cooperative Work and Social Computing (CSCW)* (pp. 662–675). New York, NY, USA: ACM Press. doi:10.1145/2675133.2675167

Wiegand, S., & Middleton, S. E. (2016). Veracity and velocity of social media content during breaking news: Analysis of November 2015 Paris shootings. In J. Bourdeau, J. Hendler, R. Nkambou, I. Horrocks, & B. Y. Zhao (Eds.), In *Proceedings of the 25th International Conference Companion on World Wide Web* (pp. 751–756). New York, NY, USA: ACM Press. doi:10.1145/2872518.2890095

Wilensky, H. (2014). Twitter as a navigator for stranded commuters during the Great East Japan earthquake. In S. R. Hiltz, L. Plotnick, M. Pfaf, & P. C. Shih (Eds.), In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. 695–704). ISCRAM.

Wulf, V., Misaki, K., Atam, M., Randall, D., & Rohde, M. (2013). "On the Ground" in Sidi Bouzid: investigating social media use during the Tunisian revolution. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW)* (pp. pp. 1409–1418). San Antonio, USA: ACM.

Yang, S., Chung, H., Lin, X., Lee, S., & Chen, L. (2013). PhaseVis: What, when, where, and who in visualizing the four phases of emergency management through the lens of social media. In T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, & T. Müller (Eds), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM)* (pp. pp. 912–917). Baden-Baden, Germany: ISCRAM.

Yates, D., & Paquette, S. (2011). Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake. *International Journal of Information Management*, *31*(1), 6–13. doi:10.1016/j.Ijinfomgt.2010(10),001.

Yin, J., Lampert, A., Cameron, M., Robinson, B., & Power, R. (2012). Using social media to enhance emergency situation awareness. *Intelligent Systemts, IEEE*, *27*(6), 52–59.

Zeng, J., Chan, C., & Fu, K. (2016). What is social media platforms' role in constructing "truth" around crisis events? A case study of Weibo's rumour management strategies after the 2015 Tianjin blasts. In The Internet, Policy & Politics Conferences.

Zipf, A. (2016). Mit Netz und Geodaten. Katastrophen-management online. *Ruperto Carola Forschungsmagazin*, *8*, 42–49.

About the Authors

Christian Reuter, PhD, is a professor for "Science and Technology for Peace and Security" (PEASEC) at Technische Universität Darmstadt and supervisor of the research group KontiKat at the University of Siegen, Germany. His research focuses on interactive and collaborative technologies such as social media in safety-critical environments, conflicts, crises, and emergencies.

Amanda Lee Hughes, PhD, is an assistant professor in the Computer Science Department at Utah State University. Prof. Hughes' research interests lie in understanding the issues that arise when information communication technologies (ICTs) are introduced into social contexts (and vice versa). Her overarching goal in conducting this type of research is to implement and deploy software systems based on deep understandings of the social context in which they reside.

Marc-André Kaufhold, MSc, is a researcher at the research group "Science and Technology for Peace and Security" (PEASEC) at Technische Universität Darmstadt and the BMBF research group KontiKat at the University of Siegen, Germany. His research focuses on continuity management, crisis information systems, and authorities' and citizens' emergency response via social media.