A Scoping Review on Agency Collaboration in Emergency Management Based on the 3C Model

Ms. Tenanoia Simona (BA, MITM, MIS)
School of Information Management, Victoria University of Wellington
Email: nanoia@gmail.com

Dr. Tauisi Taupo (corresponding author)
School of Economics, University of the South Pacific
Email: tauisi.taupo@usp.ac.fj
Phone: 679 3232611

Dr. Pedro Antunes (corresponding author)
Faculty of Sciences of the University of Lisbon
Email: pantunes@di.fc.ul.pt
Phone: +351 217 500 103

Abstract

Most emergency responses involve collaborative efforts from teams operating in the field and in the backstage. Collaboration within and across agencies should therefore be regarded as an essential service in emergency management. We propose a conceptual lens to analyse the technological support to collaboration services in emergency management. The proposed lens is based on the 3C Model, which regards collaboration services as the articulation and composition of three other services: communication, coordination and cooperation. Using this lens, we conduct a scoping literature review of the emergency management domain. The review contributes to better understand the relationships between collaboration services and technology support in emergency management.

Keywords: Collaboration Services, Emergency Management, Collaboration Model, 3C Model.

Simona, T., Taupo, T., and Antunes, P. 2021. "A Scoping Review on Agency Collaboration in Emergency Management Based on the 3C Model," Information Systems Frontiers. (https://doi.org/10.1007/s10796-020-10099-0)

1 Introduction

Intra and inter agency collaboration (local, regional and international) during an emergency can be difficult, as it depends on the nature and progression of the emergency, the collaborative capabilities of the involved agencies, and the adopted technological support (Valecha 2019). Without effective collaboration services, emergency response can easily fragment and fail, causing loss of life and property (Oh et al. 2014). Collaboration models may therefore contribute to understand the essential features of collaboration services in emergency management, highlighting in particular how agencies engage in shared activities and use technology to collaborate.

An evaluation of the status of collaboration in emergency management by the United Nations and Economic and Social Commission for Asia and the Pacific (2016) indicates the need to improve collaboration services at national and subnational levels of government. This in turn emphasises the need to also improve the technology support to collaboration services in emergency scenarios.

In this study, we adapt the 3C Model (Fuks, Raposo, Gerosa, et al. 2008) to analyse how collaboration services are realised in emergency scenarios. We characterise collaboration services as the articulation and composition of three other services, considering communication, coordination and cooperation, each supported by different technologies. We also contemplate the pre-event, during-event and post-event stages of the emergency management lifecycle.

Relying on the Adapted 3C Model (A3CM), we carry out a scoping literature review in the domain of emergency management. In particular, we analyse how the A3CM elements have been studied in the literature and their relationships to categories of technology support.

The literature review uncovers essential aspects about the articulation and composition of services involved in collaboration in emergency management. Furthermore, the scoping review also highlights the different roles of technology in supporting collaboration in emergency scenarios.

2 Adapted 3C Model

The original 3C Model has been proposed by Ellis et al. (1991) and further developed by Fuks et al. (2008) and Steinmacher et al. (2010) to help technology designers/developers analyse and deal with the collaboration needs of software applications. Collaboration is defined as a (class of) service performed by a group of people engaged in a common task and sharing a common

environment (Ellis et al. 1991). The 3C Model regards the collaboration service as resulting from the relationships of three other (classes of) services (Figure 1) (Fuks, Raposo, and Gerosa 2008): communication, coordination and cooperation. The communication service concerns the exchange of information between the participants in the collaborative activity. Coordination involves managing the participants, activities, resources, and their interdependencies. Cooperation concerns the shared production of outcomes. These services are related though supply-demand relationships, where communication supplies commitments that are managed by coordination, coordination supplies task arrangements required for cooperation, and cooperation demands more communication to maintain shared production. Collaboration, as the overarching service, is finally conceptualised as the articulation and composition of the underlying services. According to Fuks et al. (2008), the 3C Model provides a common language and conceptual tool to guide the functional specification and implementation of collaboration support.

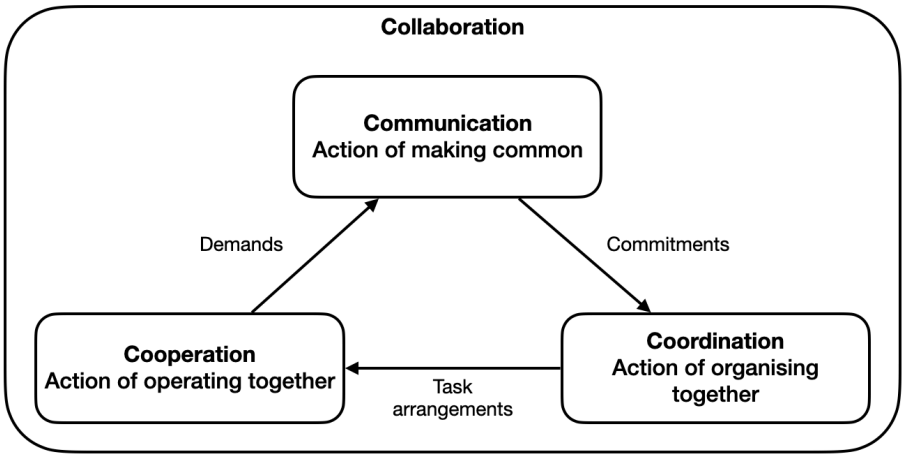

Figure 1. Main services defined by the 3C Model (Fuks, Raposo, and Gerosa 2008)

The literature on the 3C Model has been mainly centred on the technology support to collaboration in scenarios such as software development, virtual reality, and contents sharing (Medeiros et al. 2012; Modi et al. 2013; Oliveira and Gerosa 2011). For instance, Medeiros et al. (2012) used the 3C Model to design a collaborative virtual environment for maintenance operations on an oil drilling platform.

Martin et al. (2016) applied the 3C Model to the emergency management context. Their study analysed the disaster response by international organisations in the Haiti earthquake in 2010. This conceptual lens allowed them to identify a number of issues with collaboration services, including delays in recovery response, ineffective interactions between agencies, and inefficient management in response to events. These problems occurred because of inadequate

interactions between the communication, coordination and cooperation services; and also because of inadequate integration of these services in collaboration services.

2.1 Model elements

Next, we discuss the elements defined by the 3C Model in more detail.

Communication. Communication is the enabler of all other services. It can be seen as the transmission of messages containing bits of information between a sender and a receiver (Ghiuță and Prelipcean 2014). The main intentions are to share information, prepare the receivers, and influence then towards the realisation of a shared goal. A successful accomplishment of these intentions is essential for agencies operating in emergency scenarios (Ghiuță and Prelipcean 2014).

Coordination. Coordination is the process of managing the dependencies between activities, actors and other resources (Crowston 1997; Malone and Crowston 1994). Members in a group must be aware of the dynamic contributions of others, and need to actively create elements of coordination, which orient and stabilise social practices (Jarzabkowski et al. 2012).

In an emergency scenario, coordination of action is required among the different agencies and jurisdictions participating in the disaster operations (Comfort 2007). Chen et al. (2008) stress the importance of effective coordination as an essential ingredient for emergency management. Given the uncertainty, rapid evolution of events, resource constraints, and immediate decision-making demands during an emergency, effective coordination can become a challenge. Since, as suggested by the 3C Model, coordination depends on communication, a fundamental problem is how to articulate the two services to attain effective coordination. Furthermore, effective coordination involves not only adequate response, but also adequate preparedness, which may involve dealing with rules and procedures (predefined or not) (Purohit et al. 2014; Shen and Shaw 2004).

Cooperation. The classification of certain kinds of group activities as either "cooperative" or "collaborative" has seen significant debate (e.g., Oravec 1996). In some cases, the two concepts are considered equivalent (e.g., Valecha 2019). However, In this study, we regard cooperation as more specific than collaboration: "to collaborate is to work together or with someone else, and to cooperate is to work or *act together* [our emphasis] for a shared purpose" (Sørgaard

1987, p. 3). Cooperation in emergency scenarios is usually manifested as verbal and non-verbal interactions, which occur at the field-level where an actor shares goals and practices with other actors (Rossel et al. 2016). Even though, according to the 3C Model, coordination is required for cooperation, it is mostly done at the task-level, often skipping formal procedures established by organizations and jurisdictions participating in the operations (Crowston 1997).

Collaboration. As suggested by the 3C Model, collaboration services result from the articulation of communication, coordination and cooperation (Fuks, Raposo, Gerosa, et al. 2008). That is, effective collaboration in emergency management requires agencies to communicate with each other, to coordinate people, activities and resources, and to act together for a shared purpose. However, since the coordination service requires communication, and the cooperation service requires coordination, the overarching collaboration service can also be seen as a composition of the other services.

2.2 Adapting the 3C Model to the emergency management context

We now adapt the 3C Model to the emergency management context (Figure 2). In our context, the communication element refers to sharing information in emergency scenarios. Effective communication *supports* coordination between agencies, allowing them to plan and manage people, activities and resources towards improving the emergency situation. Effective communication and coordination *support* cooperation within and across agencies, allowing teams to act together toward commonly defined goals. Finally, collaboration in emergency management is supported by articulated and composite *support* from the underlying communication, coordination and cooperation services.

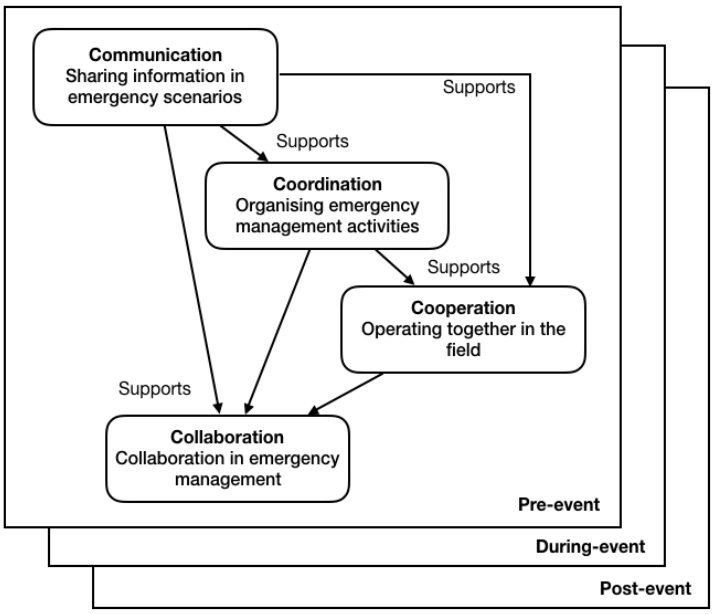

Figure 2. Adaptation of 3C Model (A3CM) to the emergency management context

Another important aspect we consider in the A3CM is that the abovementioned elements and relationships can be activated in different emergency management stages. In this study, we consider three stages: pre-event, during-event and post-event. These three stages are widely recognised in the emergency management literature as the disaster lifecycle (Mazel-Cabasse 2017). More comprehensive models, such as PPRR (Prevention/Preparedness/ Response/Recovery) (Smith et al. 2018), can still be related to the three stages, which we regard as a common denominator for analysing collaboration in emergency management. By positioning the A3CM in relation to the emergency management stages, we can better contextualise the collaboration services over the emergency management domain.

3 Review Methodology

This study adopts the scoping literature review method (Paré et al. 2015). The method seeks to examine the extent, range and nature of the available research on a topic. Scoping reviews tend to focus on the breadth of coverage of the literature rather than the depth of coverage.

The method is adequate to extract the essence of a vast body of knowledge on emergency management, mapping and synthesising key concepts underpinning the domain, and giving meaning and significance through the development of a particular viewpoint over the domain. The A3CM (Figure 2) is used to frame the review, providing a specific viewpoint over emergency management, which is centred on collaboration services provided by agencies involved in emergency management.

Prior uses of the 3C Model suggest that it may contribute to develop a relevant and unique viewpoint over the topic. In particular, we emphasise the relationships between information sharing, organisation of activities, and acting together in the field, which in turn illuminate the collaborative nature of emergency management. As noted earlier, the emergency management domain has not yet been comprehensively reviewed from a collaboration services perspective.

Since scoping reviews are mainly focused on breadth rather than depth, the method contributes to identify research foci and key knowledge elements in the domain of emergency management. The method does not bring explanatory or predictive knowledge about collaboration in the emergency management domain; it is essentially centred on thematic and regularity analysis. Next, we discuss the various steps of the literature review.

3.1 Paper selection process

The ACM Digital Library, Science Direct, and Information Systems for Crisis Response and Management (ISCRAM) Digital Library were used to search articles published from 1997 to 2016. Only peer-reviewed articles in journals and papers in conference proceedings were considered. The keywords used to search the literature are shown in Table 1.

Table 1. Keywords used to search the literature

Categories		**Keywords**
C1	Keywords specific to Emergency management	(“Emergency” OR “Crisis” OR “Disaster”) AND “Management”
C2	Keywords specific to the A3CM	(“Collaboration” OR “Collaborative” OR “Communication” OR “Coordination” OR “Cooperation” OR “Cooperative”)

Keywords in category C1 were selected because they are regularly used in the domain, which is often referred to as “emergency management”, “crisis management”, and “disaster management”. To relate the emergency management domain and the A3CM, we selected the keywords in category C2. The “collaboration” and collaborative” keywords not only cover the overarching concept in the A3CM, they also address potential conflicts in the definitions of collaboration and cooperation, as sometimes they are used to convey different meanings. Such

differences are addressed later, when coding the selected papers. The search procedure combined the keywords in categories C1 and C2 using the "AND" logical connector.

Figure 3 summarises the process of extracting, sifting, charting, and sorting the papers. From the keyword searches, we extracted a total of 451 papers. The exclusion of duplicates, anonymous, and non-English papers, resulted in 76 papers being removed from the initial data set.

An initial analysis was then conducted, which involved screening the papers' titles and abstracts to determine inclusion or exclusion. The following exclusion criteria were defined: a paper was removed from the data set if 1) not related to agencies dealing with emergency management; and 2) did not consider any A3CM element. In deciding whether to include or exclude a paper, we took a broad-minded perspective, embracing the field diversity instead of reducing it, and avoiding weakening the review for being overly strict. Through this process, a total of 273 papers were excluded and 102 papers remained in the data set.

A more detailed analysis was finally conducted on the data set, which considered the papers' full text, checking again that they were related to emergency management and addressed the A3CM elements. Through this process we excluded another 17 papers from the data set. The remaining 85 papers were finally used for data extraction and coding.

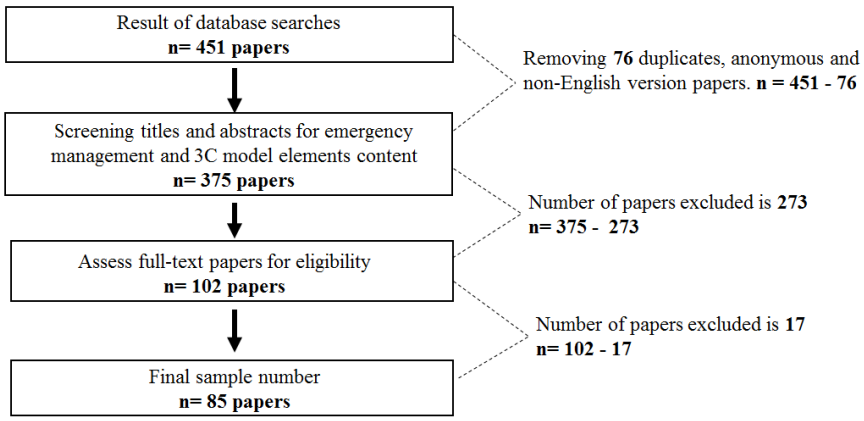

Figure 3. Overview of the paper selection process

3.2 Coding and data extraction

The 85 studies were sorted according to publication date and type of publication. Using EndNote, the studies were grouped in 5-year periods. The studies were also divided between journal articles and papers in conference proceedings. Another full-text assessment was then conducted to code relevant data using the A3CM.

The coding procedure consisted in 1) analysing data related to the A3CM elements (communication, coordination, cooperation, and collaboration); 2) identifying and classifying the types of technology involved; and 3) identifying the corresponding emergency management stages. The coding procedure adopted selective coding for the A3CM elements and emergency management stages; and adopted open coding for classifying the types of technology support (Wolfswinkel et al. 2013). Open coding allowed the researchers to capture the essential aspects of the reviewed technologies without trying to develop a detailed, predefined categorization scheme, which, given the diversity of points of view involved, would be inevitably complex (e.g., capabilities and data contributions) (Mittleman et al. 2013). The coding procedure was conducted by one author and checked for consistency by another author. Finally, the extracted data was analysed in detail and synthesised.

4 Review Results

We first profile the data set and then analyse the results based on the coded elements.

4.1 Data set profile

Figure 4 shows the publication distribution of studies in 5-year periods. An increasing trend is evident across the whole period. These results suggest an increasing relevance assigned to collaboration in the emergency management domain. Our data set indicates the trend is driven by conference papers.

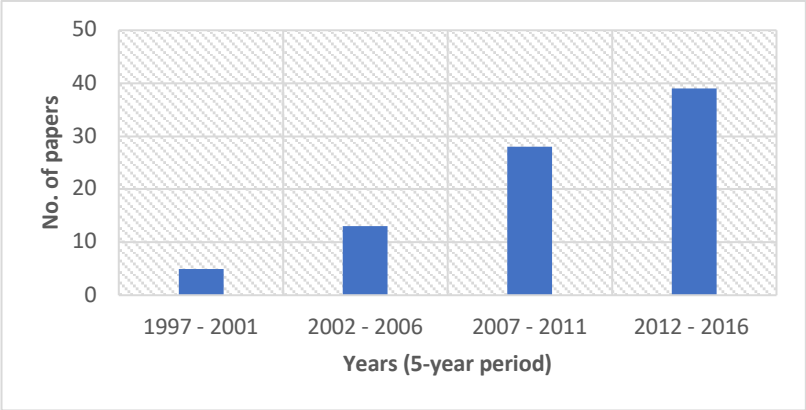

Figure 4. Distribution of reviewed papers per period

Table 2 profiles the data set considering the publication outlets and A3CM elements. Overall, studies are evenly distributed between journals and conference proceedings. The majority of conference papers come from ISCRAM, which is the major outlet in this domain.

Table 2 also shows the overall distribution of studies across the A3CM elements. We note that a study may be classified in more than one category. This profile indicates that communication has dominated the domain. The differences between communication, coordination and cooperation seem to reflect the order in which the various services tie to each other in the A3CM, with communication supporting coordination, and coordination supporting cooperation, and all supporting collaboration.

Table 2. Profile of reviewed paper

Category	Element	Number of papers
Publication outlet	Journal articles	39
	Conference papers	46
A3CM elements	Communication	49
	Coordination	25
	Cooperation	17
	Collaboration	29

The smaller relevance given to cooperation seems to reflect its more restricted nature, usually linked to the use of shared workspaces in emergency scenarios (Floch et al. 2012). Nevertheless, the concept is seen as important for improving the collaboration between agencies, both before (e.g., training, planning and simulation) and during emergencies (e.g., developing strategies) (Sabino and Rodrigues 2011).

4.2 Thematic Analysis

We now outline several themes and regularities emerging from detailed analysis of the data set.

A3CM across the emergency stages. The pre-event, during-event and post-event categories were used to understand how the A3CM relates to the emergency management cycle (Figure 5). The results indicate that a strong majority of studies concern the during-event stage. Interestingly, most studies in the during-event category have recently appeared, which may reflect a recent trend (e.g., Eleftherakis et al. 2015; Hassan and Chen-Burger 2016; Hughes et al. 2014; Oh et al. 2014; Ooms and Van Den Heuvel 2014; Purohit et al. 2014; Vivacqua et al. 2016).

The A3CM elements seem significantly less relevant in the pre-event and post-event categories. Examples in the post-event category include improving information sharing and decision making after the occurrence of events (Paul et al. 2016; Takahashi et al. 2015). Examples in the pre-event category include improving training, performance and decision-making capabilities (Bertolli et al. 2010; Keselman et al. 2005).

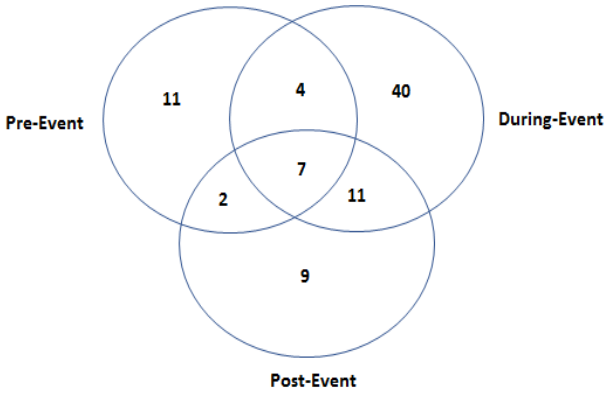

Figure 5. Categorisation of reviewed studies according to the three stages of the emergency management cycle

Apart from studies considering one stage, several studies cover two and even three stages. In fact, we found seven studies addressing all stages of an emergency. These studies emphasise the importance of effective collaboration among agents throughout the whole disaster lifecycle (Eide et al. 2012; Jung and Song 2015; Kapucu et al. 2010). They also highlight the use of technological platforms, such as geographical information systems (Trnka et al. 2005), autonomous and multi-agent systems (Abramson et al. 2007; Eleftherakis et al. 2015), coordination systems (Shen and Shaw 2004), peer-to-peer networks (Törnqvist et al. 2009), and knowledge management systems (Yao et al. 2010).

Eleven studies consider the during-event and post-event combination, which takes the lead in comparison to the other combinations. In spite of the diversity of views, a common

theme is the role of social media in building trust and disseminating information about emergencies (Busa et al. 2015; Olteanu et al. 2015; Temnikova et al. 2015).

Four studies consider the pre-event and during-event categories. Their common concern is communication, in particular how to build effective communication services between agencies before events, which will be fully utilized during events (Cinotti et al. 2010). For instance, within this category we find the development of early warning and monitoring systems, which help agencies to warn other agencies about floods, fires, inpatient flows, and other events (Epley et al. 2006; Terpstra and Vreugdenhil 2011). These improvements in inter-agency communication then promote effective collaboration.

The results show only two studies considering the pre-event and post-event stages of an emergency. Such studies are essentially concerned with the effective use of communication to improve intra and inter agency decision-making (Kapucu 2006).

Relationships between A3CM elements. Data on these relationships is relatively scarce, covering 32 studies in total (Figure 6).

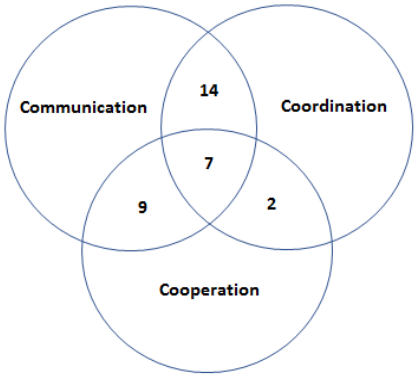

Figure 6. Relationships between the main elements of the A3CM model

The relationship between communication and coordination is the most common theme, with a total of 14 studies. These studies suggest that communication plays a key role in supporting excellent coordination among agencies in an emergency context. Several studies emphasise the relevance of social media and mobile technologies in improving coordination (De la Torre et al. 2012; Hassan and Chen-Burger 2016; Hoard et al. 2005; Meissner et al. 2006; Paul et al. 2016; Takahashi et al. 2015; Temnikova et al. 2015).

Surprisingly, only two studies were found relating coordination and cooperation. This result is puzzling because it is commonly accepted that coordination arranges tasks for cooperation (Fuks, Raposo, Gerosa, et al. 2008). Most studies in this combination discuss

situations where different agencies must deal with emergencies that require a concerted effort, as the required decisions/actions exceed the capacity of a single agency (Steigenberger 2015). These situations then require bringing effective coordination support to the cooperation (De Koning et al. 2011).

The nine studies relating cooperation and communication focus on infrastructural requirements to improve cooperation in emergency contexts. Examples include making improvements in wireless networks, which enable agencies to better cooperate in the field (Cheikhrouhou 2016; Cinotti et al. 2010; ODell 2008; Ribeiro and Ferworn 2010). These improvements often involve low-level analysis of the infrastructures used by agencies, for instance the police, which helps them to operate more effectively is shared spaces. Other aspects considered in this category include improving network setup times, inter-operability, flexibility, and data standardisation (Klappenbach et al. 2004; Törnqvist et al. 2009; Trnka et al. 2005). Finally, the intersection of the three circles in Figure 6 once again highlights the relevance of integrating communication, coordination and cooperation services in emergency management, as suggested by A3CM. We found seven studies considering such integration (e.g., Cheikhrouhou 2016).

A3CM and technology support. Figure 7 shows the distribution of studies according to technology support categories and A3CM elements. We identified seven major categories of technology support in the reviewed studies: mobile systems, early warning systems, social media, remote sensing and GIS, IT infrastructure, integration platforms, and collaborative systems. The last category on the right in Figure 7 refers to studies in the data set that do not concern any type of technology.

One of the most relevant technologies in the data set concerns IT infrastructure. This category includes studies on the use of networking, internet, web, and cloud technology, and their integrated management by agencies (Cheikhrouhou 2016; Iapichino et al. 2009; Ribeiro and Ferworn 2010; Tarchi et al. 2009). In general, these technologies seek to improve flexibility, mobility, security, reliability, scalability, and interoperability in emergency management.

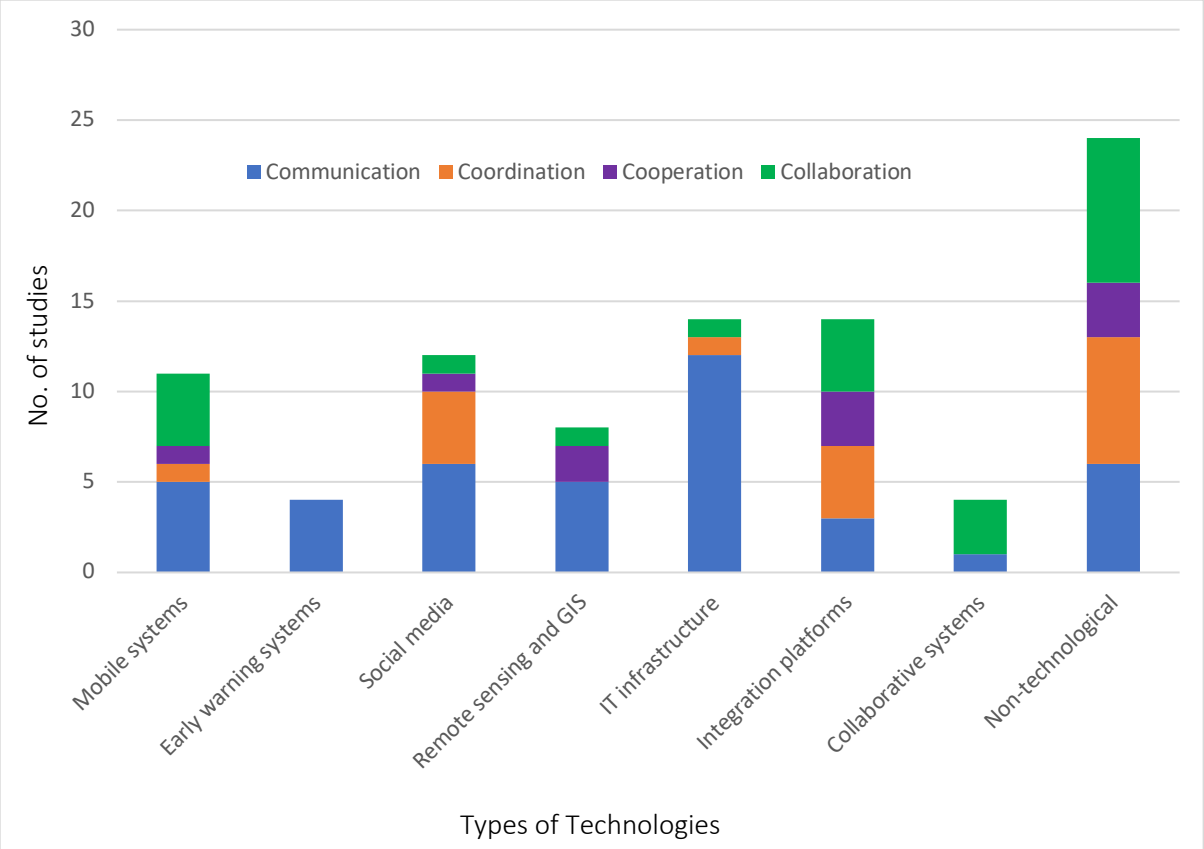

Figure 7. Identified categories of technology support and discussed E3CM elements

Tied in terms of relevance with IT infrastructure, we find integration platforms. This broad category considers the integration of a variety of building blocks and supporting tools that can be used to improve the performance of emergency response teams, including architectures (e.g., peer-to-peer), systems (e.g., agent systems) and applications (e.g., simulation) (Abramson et al. 2007; Catarci et al. 2008; Honkavuo et al. 2015).

Social media also emerges from the data set as a relevant type of technology. Most studies in this area concern the dissemination of second-hand information when coordinating relief efforts; and the analysis of trends to build situational information (Busa et al. 2015; Cameron et al. 2012; Ghosh et al. 2018; Hughes et al. 2014; Olteanu et al. 2015; Reuter et al. 2013; Takahashi et al. 2015; Temnikova et al. 2015). Other studies consider the possibilities brought by crowdsourcing in gathering data, participating and solving societal problems during emergencies (Callaghan 2016; Ogie et al. 2018; Poblet et al. 2018).

Social media are seen as complex when it comes to emergency management, due to their dynamic nature, and also difficulties performing coordination services on top of this technology (Shen and Shaw 2004). Nevertheless, studies suggest that agencies can coordinate and even cooperate through social media (Reuter et al. 2013).

Next, we find mobile systems. Studies in this area adopt wireless networks and mobile devices to design and develop emergency response systems with a focus on improving decision making (Krasovec 2004; Kung et al. 2008; Meissner et al. 2006). The lack of up-to-date information from the field is considered a key reason behind poor decision making and lack of coordination (Hassan and Chen-Burger 2016; Paul et al. 2016).

Remote sensing and GIS technologies emerge from the data set as less relevant than the technologies above. Nevertheless, studies in this area highlight the important role that remote sensing and GIS play in supporting a spatial approach to emergency management (Sabino and Rodrigues 2011). Such approach also emphasises the adoption of shared and smart workspaces to support cooperation, which can increase the efficiency and effectiveness of teams in the field (Floch et al. 2012).

Early warning systems seem to be a niche technology, which is essentially centred on communication. They support timely information diffusion during emergencies (Terpstra and Vreugdenhil 2011; Zacarese 2013).

Collaborative systems is another niche technology, which has been essentially centred on the support to ad hoc group practices such as collaborative interpretation of events, ad hoc coordination and self-organisation (Bunker et al. 2015; Wiedenhöfer et al. 2011). One possible reason for the lack of relevance of this category may be the weak link to communication (in fact, the weakest across the seven categories). As communication is perceived as extremely relevant to emergency management, a lack of consideration for this dimension may reduce its perceived relevance.

Out of the seven technologies identified in this review, only four address the cooperation service. These four technologies are mobile systems, social media, remote sensing and GIS, and integration platforms. Surprisingly, we found out that collaborative systems have been studied in relation to the overarching collaboration service, but not the cooperation service. One possible explanation could be an equivocal understanding of cooperation, which may be regarded as not independent from collaboration.

The integration platforms category exhibits the most coverage of the cooperation service. Studies suggest that integration platforms are necessary to integrate the different operative models used by agencies in emergency contexts (Honkavuo et al. 2015). Such infrastructure helps developing a common framework for stakeholder cooperation. Interestingly, the integration platforms category also shows an even spread of the A3CM elements, while the other categories seem to emphasise specific combinations. The systemic characteristic of this category emphasises the holistic viewpoint provided by the A3CM.

5 Discussion

In this research, we propose a conceptual lens to understand collaboration services in emergency situations. This conceptual lens regards collaboration services as the articulation and composition of three other services (communication, coordination and cooperation), each supported by different types of technology. To the best of our knowledge, only one prior study has applied such a conceptual lens in the emergency management domain (Martin et al. 2016). And yet, we find an increasing trend of publications giving relevance to collaboration in emergency management. Many studies appeared recently, which may signpost an increasing number of emergency events, a growing preoccupation with how agencies face emergencies, and a growing need to deliver better collaboration services across and within agencies.

Our review highlights that agencies can improve collaboration services through better articulation and composition of communication, coordination and cooperation services. These services can be realised with support from a variety of technologies such as mobile systems, social networks, and collaborative systems. However, most research shows a strong concern with one particular service, communication, which in turn also skews technology support towards communication.

In our review, we also found a substantial number of studies centred on the during-event stage of emergency management; and a very small number of studies discussing the post-event stage. Even though collaboration services are very relevant in the during-event phase, it seems that the development of innovative systems capable to integrate the collaboration service across all stages of an emergency would be useful. Such integration would support agencies better planning, preparing and learning from emergencies.

Interestingly, even though we found a similar number of studies addressing the pre-event and the post-event stages, very few studies show a common concern with the two stages. On the other hand, the combinations of pre-event and during-event, and of during-event and post-event, are frequent. One possible reason could be the lack of conceptual frameworks regarding collaboration across the whole emergency management lifecycle. The A3CM could provide such a conceptual framework.

Our thematic analysis shows some remarkable indications when the A3CM elements are considered against technology categories. Clearly, mobile systems, social media, and integration platforms are the more commonly considered categories. In particular, we find that mobile systems are widely seen as essential to improve the communication and collaboration

among agencies, whereas integration platforms are largely seen as essential to improve coordination and collaboration.

Social media have been studied more in relation to communication and coordination, and less to cooperation and collaboration. IT infrastructure has been widely studied in relation to communication and less for the purposes of coordination and collaboration.

We found a relative lack of interest in the study of collaborative systems for emergency management. One possible reason may be the lack of integration with communication services. We suggest that future developments in this area should better integrate the communication dimension, as a way to increase relevance.

The A3CM also gives indications regarding the dependencies between collaboration services. A much stronger relationship was witnessed between communication and coordination, and between communication and cooperation, than between coordination and cooperation. One reason that might contribute to this weak relationship is that most studies relating coordination and cooperation fell under the non-technological category.

Overall, the A3CM contributes to better understand collaboration services in the emergency management domain, which emphasises the articulation and composition of other services. The composite nature of the A3CM highlights that the collaboration service results from the composition of other services and technologies. The different weights assigned to communication, coordination and cooperation, emphasise this composite nature. From this conceptual lens, we can realise how different technologies support the overarching collaboration service through the composition of other services. In particular, by analysing how communication supports coordination, how coordination supports cooperation, and finally how the three services together support collaboration, we can better understand how collaboration is realised. Furthermore, by also considering the emergency management lifecycle, we can also better understand the relationships between technological support and collaboration in the emergency domain.

6 Conclusion

The dynamic nature of emergencies requires collaboration among the agencies involved in emergency management; and technology often plays a critical in supporting collaboration services. This study proposes the A3CM as a conceptual lens for understanding the use of technology in emergency management, considering the pre-event, during-event and post-event scenarios. Based on the A3CM, we provide a scoping review of the emergency management

literature addressing the collaboration between agencies and the technology support to collaboration services.

We regard the A3CM as essential to understand how collaboration service results from the articulation and composition of other services, namely communication, coordination and cooperation. This viewpoint provides conceptual structure for further research on collaboration services, disentangling the supportive relationships between communication and coordination, coordination and cooperation, and their individual roles in supporting the overarching collaboration services.

Our review indicates that a wide body of research has been devoted to the communication service, followed by a reasonable number of studies investigating the synergies between communication and coordination services. However, the cooperation service seems significantly neglected.

Since A3CM also distinguishes the different stages in an emergency, we can also report on the body of research according to them. Our review highlights that research has been more centred on the during-event stage, followed by the combination of during-event and post-event.

Our study also provides a conceptual lens helping to understand the relationships between collaboration services and technology support in emergency management. Such lens brings clarity regarding the different roles of technology in emergency management. It also highlights which areas of research have been dominant. We identified seven categories of technologies supporting collaboration services. The ones that received most attention have been integration platforms, mobile systems, and IT infrastructure. We observed that few studies consider collaborative systems. One possible explanation is that collaborative systems have not taken sufficient consideration of the communication service.

Given the complex and dynamic nature of emergencies, understanding the relationship between the A3CM elements can help researchers and practitioners focus their attention on small improvements in the development of collaboration services. Agencies may also benefit in terms of improving their decision making for choosing the most effective collaboration support technologies.

The A3CM also opens up some interesting avenues for future research. In particular, we envisage a more nuanced characterisation of the support relationships between the A3CM elements. The notions of articulation and composition in the collaboration service can also be further explored. Future research may also consider reframing collaborative systems using a broader perspective, giving more relevance to the service mix.

7 References

Abramson, M., Chao, W., Macker, J., & Mittu, R. (2007). Coordination in disaster management and response: a unified approach. In *International Conference on Autonomous Agents and Multiagent Systems* (pp. 162–175). Springer.

Bertolli, C., Tarchi, D., Fantacci, R., Vanneschi, M., & Tassi, A. (2010). An Integrated Communication-computing Solution in Emergency Management. In *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference* (pp. 651–655). New York, NY, USA: ACM.

Bunker, D., Levine, L., & Woody, C. (2015). Repertoires of collaboration for common operating pictures of disasters and extreme events. *Information Systems Frontiers*, *17*(1), 51–65.

Busa, M., Musacchio, M., Finan, S., & Fennell, C. (2015). Trust-building Through Social Media Communications in Disaster Management. In *Proceedings of the 24th International Conference on World Wide Web* (pp. 1179–1184). New York, NY, USA: ACM.

Callaghan, C. (2016). Disaster management, crowdsourced R&D and probabilistic innovation theory: Toward real time disaster response capability. *International Journal of Disaster Risk Reduction*, *17*, 238–250.

Cameron, M., Power, R., Robinson, B., & Yin, J. (2012). Emergency Situation Awareness from Twitter for Crisis Management. In *Proceedings of the 21st International Conference on World Wide Web* (pp. 695–698). New York, NY, USA: ACM.

Catarci, T., Leoni, M., Marrella, A., Mecella, M., Salvatore, B., Vetere, G., et al. (2008). Pervasive Software Environments for Supporting Disaster Responses. *IEEE Internet Computing*, *12*(1), 26–37.

Cheikhrouhou, O. (2016). Secure Group Communication in Wireless Sensor Networks: A survey. *Journal of Network and Computer Applications*, *61*, 115–132.

Chen, R., Sharman, R., Rao, H., & Upadhyaya, S. (2008). Coordination in emergency response management. *Communications of the ACM*, *51*(5), 66–73.

Cinotti, M., Orefice, P., Paura, L., & Scarpiello, A. (2010). Performance Analysis of a QoS Management Architecture for an Emergency Scenario. In *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference* (pp. 514–518). New York, NY, USA: ACM.

Comfort, L. (2007). Crisis management in hindsight: Cognition, communication, coordination, and control. *Public Administration Review*, *67*, 189–197.

Crowston, K. (1997). A coordination theory approach to organizational process design. *Organization Science*, *8*(2), 157–175.

De Koning, L., Kuijt-Evers, L., Theunissen, N., & Van Rijk, R. (2011). Multidisciplinary Cooperation in Crisis Management Teams: A Tool to Improve Team Situation Awareness. Presented at the 8th International ISCRAM Conference, Lisbon, Portugal.

De la Torre, L., Dolinskaya, I., & Smilowitz, K. (2012). Disaster relief routing: Integrating research and practice. *Socio-Economic Planning Sciences*, *46*(1), 88–97.

Eide, A., Haugstveit, I., Halvorsrud, R., Skjetne, J., & Stiso, M. (2012). Key challenges in multiagency collaboration during large-scale emergency management. In *AmI for crisis management, international joint conference on ambient intelligence, Pisa, Italy*.

Eleftherakis, G., Kostic, M., Rousis, K., & Vasilescu, A. (2015). Stigmergy Inspired Approach to Enable Agent Communication in Emergency Scenarios. In *Proceedings of the 7th Balkan Conference on Informatics Conference*. New York, NY, USA: ACM.

Ellis, C., Gibbs, S., & Rein, G. (1991). Groupware: some issues and experiences. *Communications of the ACM*, *34*(1), 39–58.

Epley, E., Stewart, R., Love, P., Jenkins, D., Siegworth, G., Baskin, T., et al. (2006). A regional medical operations center improves disaster response and inter-hospital trauma transfers. *The American Journal of Surgery*, *192*(6), 853–859.

Floch, J., Angermann, M., Jennings, E., & Roddy, M. (2012). Exploring cooperating smart spaces for efficient collaboration in disaster management. Presented at the 9th International ISCRAM Conference, Vancouver, Canada.

Fuks, H., Raposo, A., & Gerosa, M. (2008). The 3C collaboration model. In *Encyclopedia of E-collaboration* (pp. 637–644). IGI Global.

Fuks, H., Raposo, A., Gerosa, M., Pimentel, M., Filippo, D., & Lucena, C. (2008). Inter- and intra-relationships between communication coordination and cooperation in the scope of the 3C Collaboration Model. In *12th International Conference on Computer Supported Cooperative Work in Design* (pp. 148–153). IEEE.

Ghiuță, O., & Prelipcean, G. (2014). Communication in the emergency situations management. *The USV Annals of Economics and Public Administration*, *14*(2 (20)), 122–130.

Ghosh, S., Ghosh, K., Ganguly, D., Chakraborty, T., Jones, G., Moens, M., & Imran, M. (2018). Exploitation of social media for emergency relief and preparedness: Recent research and trends. *Information Systems Frontiers*, *20*(5), 901–907.

Hassan, M., & Chen-Burger, Y.-H. (2016). Communication and Tracking Ontology Development for Civilians Earthquake Disaster Assistance. Presented at the ISCRAM 2016 Conference, Rio de Janeiro, Brazil.

Hoard, M., Homer, J., Manley, W., Furbee, P., Haque, A., & Helmkamp, J. (2005). Systems modeling in support of evidence-based disaster planning for rural areas. *International Journal of Hygiene and Environmental Health*, *208*(1–2), 117–125.

Honkavuo, H., Jähi, M., Kosonen, A., Piira, K., Rannat, K., Soininen, J., et al. (2015). Enhancing the quality of contingency planning by simulation. Presented at the ISCRAM 2015 Conference, Palen, Büscher.

Hughes, A., St. Denis, L., Palen, L., & Anderson, K. (2014). Online Public Communications by Police & Fire Services During the 2012 Hurricane Sandy. In *Proceedings of the 32nd Annual ACM*

Conference on Human Factors in Computing Systems (pp. 1505–1514). New York, NY, USA: ACM.

Iapichino, G., Bonnet, C., Herrero, O., Baudoin, C., & Buret, I. (2009). Combining Mobility and Heterogeneous Networking for Emergency Management: A PMIPv6 and HIP-based Approach. In *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly* (pp. 603–607). New York, NY, USA: ACM.

Jarzabkowski, P., Lê, J., & Feldman, M. (2012). Toward a theory of coordinating: Creating coordinating mechanisms in practice. *Organization Science*, *23*(4), 907–927.

Jung, K., & Song, M. (2015). Linking emergency management networks to disaster resilience: bonding and bridging strategy in hierarchical or horizontal collaboration networks. *Quality & Quantity*, *49*(4), 1465–1483.

Kapucu, N. (2006). Interagency Communication Networks During Emergencies: Boundary Spanners in Multiagency Coordination. *The American Review of Public Administration*, *36*(2), 207–225.

Kapucu, N., Arslan, T., & Demiroz, F. (2010). Collaborative emergency management and national emergency management network. *Disaster prevention and management: An international journal*, *19*(4).

Keselman, A., Slaughter, L., & Patel, V. (2005). Toward a framework for understanding lay public's comprehension of disaster and bioterrorism information. *Journal of Biomedical Informatics*, *38*(4), 331–344.

Klappenbach, D., Hollfelder, S., Meissner, A., & Wilbert, S. (2004). From analog voice radio to ICT: Data communication and data modeling for the German NBC reconnaissance vehicle. Presented at the 2004 International ISCRAM Conference, Brussels, Belgium.

Krasovec, K. (2004). Auxiliary technologies related to transport and communication for obstetric emergencies. *International Journal of Gynecology & Obstetrics*, *85, Supplement 1*, S14–S23.

Kung, H.-Y., Ku, H.-H., Wu, C.-I., & Lin, C.-Y. (2008). Intelligent and situation-aware pervasive system to support debris-flow disaster prediction and alerting in Taiwan. *Journal of Network and Computer Applications*, *31*(1), 1–18.

Malone, T., & Crowston, K. (1994). The interdisciplinary study of coordination. *ACM Computing Surveys*, *26*(1), 87–119.

Martin, E., Nolte, I., & Vitolo, E. (2016). The Four Cs of disaster partnering: communication, cooperation, coordination and collaboration. *Disasters*, *40*(4), 621–643.

Mazel-Cabasse, C. (2017). Hybrid disasters—Hybrid knowledge. *Resilience: A New Paradigm of Nuclear Safety. From Accident Mitigation to Resilient Society Facing Extreme Situations*, 337–351.

Medeiros, D., Ribeiro, E., Dam, P., Pinheiro, R., Motta, T., Loaiza, M., & Raposo, A. (2012). A Case Study on the Implementation of the 3C Collaboration Model in Virtual Environments (pp. 147–154). Presented at the 14th Symposium on Virtual and Augmented Reality, IEEE.

Meissner, A., Wang, Z., Putz, W., & Grimmer, J. (2006). Mikobos-a mobile information and communication system for emergency response (pp. 92–101). Presented at the 3rd International ISCRAM Conference, Newark, NJ, USA.

Mittleman, D., Murphy, J., & Briggs, R. (2013). Classification of collaboration technology. In *Collaboration Systems: Concept, Value, and Use* (p. 42). Armonk, New York, London, England: M.E.Sharpe.

Modi, S., Abbott, P., & Counsell, S. (2013). Negotiating Common Ground in Distributed Agile Development: A Case Study Perspective (pp. 80–89). IEEE.

ODell, P. (2008). Communities of Trust. Presented at the 5th International ISCRAM Conference, Washington, DC, USA.

Ogie, R. I., Forehead, H., Clarke, R., & Perez, P. (2018). Participation patterns and reliability of human sensing in crowd-sourced disaster management. *Information Systems Frontiers*, *20*(4), 713–728.

Oh, N., Okada, A., & Comfort, L. (2014). Building Collaborative Emergency Management Systems in Northeast Asia: A Comparative Analysis of the Roles of International Agencies. *Journal of Comparative Policy Analysis: Research and Practice*, *16*(1), 94–111.

Oliveira, L., & Gerosa, M. (2011). Collaborative features in content sharing web 2.0 social networks: A domain engineering based on the 3c collaboration model. In *International Conference on Collaboration and Technology* (pp. 142–157). Springer.

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.

Ooms, D., & Van Den Heuvel, W. (2014). If Every Nail Looks Different, You Need Different Hammers: Modeling Civil-Military Interaction. Presented at the 11th International ISCRAM Conference, Pennsylvania, USA.

Oravec, J. A. (1996). *Virtual individuals, virtual groups* (First.). US: Cambridge University Press.

Paré, G., Trudel, M., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management*, *52*(2), 183–199.

Paul, P., Dutta, H., Ghosh, B., Hazra, K., Chakraborty, S., Saha, S., & Nandi, S. (2016). Offline Crisis Mapping by Opportunistic Dissemination of Crisis Data After Large-scale Disasters. In *Proceedings of the Second ACM SIGSPATIAL International Workshop on the Use of GIS in Emergency Management* (pp. 1–8). New York, NY, USA: ACM.

Poblet, M., García-Cuesta, E., & Casanovas, P. (2018). Crowdsourcing roles, methods and tools for data-intensive disaster management. *Information Systems Frontiers*, *20*(6), 1363–1379.

Purohit, H., Bhatt, S., Hampton, A., Shalin, V., Sheth, A., & Flach, J. (2014). With Whom to Coordinate, Why and How in Ad-hoc Social Media Communities during Crisis Response. In *Proceedings of the 11th International Conference on Information Systems for Crisis Response and Management. University Park, Pennsylvania*.

Reuter, C., Heger, O., & Pipek, V. (2013). Combining Real and Virtual Volunteers through Social Media. Presented at the 10th International ISCRAM Conference, Baden-Baden, Germany.

Ribeiro, C., & Ferworn, A. (2010). Computational Public Safety in Emergency Management Communications. In *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference* (pp. 656–660). New York, NY, USA: ACM.

Rossel, P., Herskovic, V., & Ormeño, E. (2016). Creating a family of collaborative applications for emergency management in the firefighting sub-domain. *Information Systems Frontiers*, *18*(1), 69–84.

Sabino, A., & Rodrigues, A. (2011). Understanding the Role of Cooperation in Emergency Plan Construction. Presented at the 8th International ISCRAM Conference, Lisbon, Portugal.

Shen, S., & Shaw, M. (2004). Managing coordination in emergency response systems with information technologies. In *AMCIS 2004 Proceedings* (p. 252).

Smith, E., Burkle, F., Aitken, P., & Leggatt, P. (2018). Seven decades of disasters: a systematic review of the literature. *Prehospital and disaster medicine*, *33*(4), 418–423.

Sørgaard, P. (1987). *A cooperative work perspective on use and development of computer artifacts*. Aarhus Universitet, Matematisk Institut, Datalogisk Afdeling.

Steigenberger, N. (2015). Organizing for the Big One – A Review of Case Studies on Multi-Agency Disaster Response and a Research Agenda. Presented at the ISCRAM 2015 Conference, Palen, Büscher.

Steinmacher, I., Chaves, A., & Gerosa, M. (2010). Awareness support in global software development: a systematic review based on the 3C collaboration model. In *International Conference on Collaboration and Technology* (pp. 185–201). Springer.

Takahashi, B., Tandoc Jr., E., & Carmichael, C. (2015). Communicating on Twitter during a disaster: An analysis of tweets during Typhoon Haiyan in the Philippines. *Computers in Human Behavior*, *50*, 392–398.

Tarchi, D., Fantacci, R., & Marabissi, D. (2009). The Communication Infrastructure for Emergency Management: The In.Sy.Eme. Vision. In *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly* (pp. 618–622). New York, NY, USA: ACM.

Temnikova, I., Vieweg, S., & Castillo, C. (2015). The Case for Readability of Crisis Communications in Social Media. In *Proceedings of the 24th International Conference on World Wide Web* (pp. 1245–1250). New York, NY, USA: ACM.

Terpstra, T., & Vreugdenhil, H. (2011). Filling in the Blanks: Constructing Effective Flood Warning Messages Using the Flood Warning Communicator (FWC). Presented at the 8th International ISCRAM Conference, Lisbon, Portugal.

Törnqvist, E., Sigholm, J., & Tehrani, S. (2009). Hastily Formed Networks for Disaster Response: Technical Heterogeneity and Virtual Pockets of Local Order. Presented at the 6th International ISCRAM Conference, Gothenburg, Sweden.

Trnka, J., Le Duc, M., & Sivertun, Å. (2005). Inter-organizational Issues in ICT, GIS and GSD - Mapping Swedish Emergency Management at the Local and Regional Level. Presented at the 2nd International ISCRAM Conference, Brussels, Belgium.

United Nations, & Economic and Social Commission for Asia and the Pacific. (2016). *Disasters without borders: Regional resilience for sustainable development . Asia-Pacific disaster report 2015*.

Valecha, R. (2019). An investigation of interaction patterns in emergency management: A case study of the crash of continental flight 3407. *Information Systems Frontiers*, 1–13.

Vivacqua, A., Garcia, A., Canós, J., Comes, M., & Vieira, V. (2016). Collaboration and Decision Making in Crisis Situations. In *Proceedings of the 19th ACM Conference on Computer Supported Cooperative Work and Social Computing Companion* (pp. 503–508). New York, NY, USA: ACM.

Wiedenhöfer, T., Reuter, C., Ley, B., & Pipek, V. (2011). Inter-Organizational Crisis Management Infrastructures for Electrical Power Breakdowns. Presented at the 8th International ISCRAM Conference.

Wolfswinkel, J., Furtmueller, E., & Wilderom, C. (2013). Using grounded theory as a method for rigorously reviewing literature. *European journal of information systems*, *22*(1), 45–55.

Yao, X., Turoff, M., & Hiltz, R. (2010). A Field Trial of a Collaborative Online Scenario Creation System for Emergency Management. Presented at the 7th International ISCRAM Conference, Seattle, USA.

Zacarese, L. (2013). Emergency communications – Getting the message right. *Journal of Chemical Health and Safety*, *20*(3), 45–46.