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A systematic literature review on information systems for disaster management and proposals for its future research agenda

Diana Fischer-Pressler
University of Bamberg, diana.fischer-pressler@uni-bamberg.de

Dario Bonaretti
Nova Southeastern University, dbonaret@nova.edu

A SYSTEMATIC LITERATURE REVIEW ON INFORMATION SYSTEMS FOR DISASTER MANAGEMENT AND PROPOSALS FOR ITS RESEARCH AGENDA

Research Paper

Diana Fischer-Preßler, University of Bamberg, Bamberg, Germany, diana.fischer-pressler@uni-bamberg.de

Dario Bonaretti, Nova Southeastern University, Florida, dbonaret@nova.edu

Abstract

Emergency management information systems (EMIS) are fundamental for responding to disasters effectively since they provide and process emergency-related information. A literature stream has emerged that corresponds with the increased relevance of the wide array of different information systems that have been used in response to disasters. In addition, the discussion around systems used primarily within responder organizations broadened to systems such as social media that are open to the general public. However, a systematic review of the EMIS literature stream is still missing. This literature review presents a timeline of EMIS research from 1990 up to 2021. It shows the types of information system scholars focused on, and what disaster response functions they supported. It furthermore identifies challenges in EMIS research and proposes future research directions.

Keywords: Disaster Response, Emergency Management, Digitalization, Literature Review, Information Systems.

1 Introduction

Disasters such as floods, terrorist attacks, or epidemics pose severe threats to the wellbeing of modern societies (Ansell et al., 2010; Quarantelli et al., 2018). A major challenge of managing disasters is they are often transboundary, that is, they cross national, political, and organizational boundaries. Transboundary crises spread quickly around the globe, their origin is often unclear in the beginning, they bring a large number of direct and indirect victims, and traditional approaches from local response organizations may not necessarily work (Quarantelli et al., 2018). To respond to such new threats but also “traditional” disasters (e.g., flooding, forest fires), emergency responders use information systems hereafter referred to as emergency management information systems (EMIS) that help them to manage a disaster effectively.

An EMIS is an information system that supports activities in disaster mitigation, preparation, response, and recovery by storing, processing, or exchanging emergency-related information (Turoff et al., 2004). Examples of EMIS are professional response software, databases, or radio equipment (e.g., Allen et al., 2014; Chen et al., 2008), emergency apps (Tan et al., 2017; Fischer-Preßler et al., 2020), or open-source software (e.g., Currion et al., 2007). Alongside these technologies dedicated to emergency management, technological progress in recent years broadened the spectrum of technologies that have been used in emergency management, such as social media (Ling et al., 2015) and crowdsourcing platforms that also enable the public to act more visibly.

A growing number of papers in recent years shows how the use of EMIS can assist with disaster response. Scholars are concerned with diverse research questions, ranging from how social media supports communication between authorities and the public (e.g., Ling et al., 2015; Tim et al., 2017), how EMIS enable collaboration between emergency responders (Allen et al., 2014), how effective disaster-related data exchange may look like (Chen et al., 2013), what factors hinder effective information supply chains (Day et al., 2009), and what drives adoption and use of EMIS (Fischer-Preßler et al., 2021a; Han et al., 2015; Petter and Fruhling, 2011).

Although we can assume that EMIS facilitates emergency management, little is known about the main functions of EMIS. Currently, the EMIS field lacks a comprehensive review of the subject, and scholars show little agreement even when it comes to adopting common conceptualizations on terminology. Prior reviews have adopted a siloed perspective, pivoting on a certain type of technology such as social media or emergency applications (e.g., Reuter et al., 2018; Simon et al., 2015; Tan et al., 2017). However, while research on social media is prevalent in IS research (Bonaretti and Piccoli, 2018), that is not what professional emergency responders' are mostly concerned with. In this paper, we review studies from the IS discipline on emergency management to provide an overview of EMIS research. By doing so, we aim to articulate current challenges to answer the following research question:

What research directions shall scholars pursue to address current challenges in EMIS research?

To answer our RQ, we conducted a systematic literature review that summarizes the types of EMIS artifacts that have been studied in IS literature, as well as the emergency management functions that they support. In particular, the article is structured as follows. We start with a theoretical introduction and define disaster and emergency management. This section is followed by the presentation of the literature review criteria. Subsequently, we present a historical overview of technical artifacts. In the section that follows, we introduce functions that EMIS typically support. Finally, we discuss future research directions that EMIS researchers can take and end with limitations and a conclusion.

2 Theoretical Background on Disaster and Emergency Management

Disasters are events that cause serious physical harm and social disruption. They can be natural (e.g., floods, major fires, hurricanes), human-made (e.g., terrorist attack, war, active shooter, or nuclear meltdowns), or a combination of both (e.g., a nuclear meltdown resulting from a hurricane and earthquake). Such events unfold in chaotic and turbulent contexts, the "domain of rapid response" (Snowden and Boone, 2007, p. 5), with unclear cause-effect relationships and acute time pressure. Emergency response is driven by the need to maintain or restore a functioning social system amid the disruption caused by the disaster (e.g., Kreps, 1985; Quarantelli et al., 2018).

In contrast to emergencies, disasters cannot be handled by the resources (e.g., human, material) of the affected community only; rather resources from outside the community are necessary to cope with the event. Emergency, instead, are events that responders are fully skilled to handle as they are relatively routine (McEntire, 2006). However, the distinction between emergencies and disasters is blurred in the IS discipline. This means EMIS research indistinctly includes areas that have been referred to as "emergency," "crisis," or "disaster" management.

Despite its name, research in emergency management—at times also referred to as crisis or disaster management (e.g., Boin et al., 2005)—often focuses on disasters rather than emergencies because responders are fully skilled to address most needs in routine emergencies. Emergency management (EM) is the "managerial function which arranges counter-measures and coordinates involved organizations, resources and information to prevent, mitigate, respond to, recover from or prepare for a disaster and therefore reduce the overall vulnerability of communities and infrastructures to known and unknown threats" (Vogt et al., 2011, p. 2). Response organizations involved in professional emergency management are from law enforcement, public authorities, firefighting, or paramedics.

Scholars distinguish four phases of emergency management: mitigation, preparedness, response, and recovery. Most of the literature in EMIS focuses on the response and short-term recovery phases, which constitute the core of "emergency management" (Fischer et al., 2016). In this paper, we, hence, concentrate on the response phase and the functions EMIS provide to support professional emergency responders to handle the situation.

3 Methodology

To answer our research questions, we conducted a systematic literature review (Paré et al., 2015). The review process included a keyword-based search in four indexing databases, a systematic selection of relevant papers, a forward and backward search on the papers of the subject-area screen, and the analysis of the selected paper.

First, we conducted a keyword-based search in the following databases: the AIS electronic library, JSTOR, EBSCOhost, and ScienceDirect. We build our search terms based on the two core concepts: information system and disaster. Thus, we searched for ("emergency" OR "disaster" OR "crisis" OR "catastrophe") AND ("information system") in the title, abstract, and keywords field of each database, and limited publication years from 1990 up to 2021. Our query retrieved 4,067 hits.

Second, journal quality screening led to retaining only articles published in outlets ranked as B or higher on the 2019 ABDC journal quality list or the VHB ranking. We furthermore retained only full papers (and excluded research-in-progress or short papers) published in the proceedings of the "International Conference on Information Systems" and the "European Conference on Information Systems" and articles not written in English. This step resulted in 824 papers. Third, we read abstracts and titles to exclude papers that did not pertain to either managing disaster or information systems, thereby excluding 648 papers resulting in 176 papers.

Fourth, subject area screening focused on retaining only research whose audience is IS scholars. Therefore, we included only articles from outlets categorized as "Information Systems (0806)" on the ABDC list, or as "WI" (i.e., "Wirtschaftsinformatik") on the VHB list. This step resulted in 31 papers. No further restrictions on the genre of articles were included, thus retaining empirical, conceptual, design, and review papers.

In addition to the keyword-based search, we conducted forward and backward searches to identify papers that had cited previously included papers or that had been cited by them. We selected from the remaining papers for further analysis all those that passed the same format, content, and subject area screening steps described above. This resulted in a total of 19 additional papers and a final set of 50 papers in total. Figure 1 shows the paper selection process.

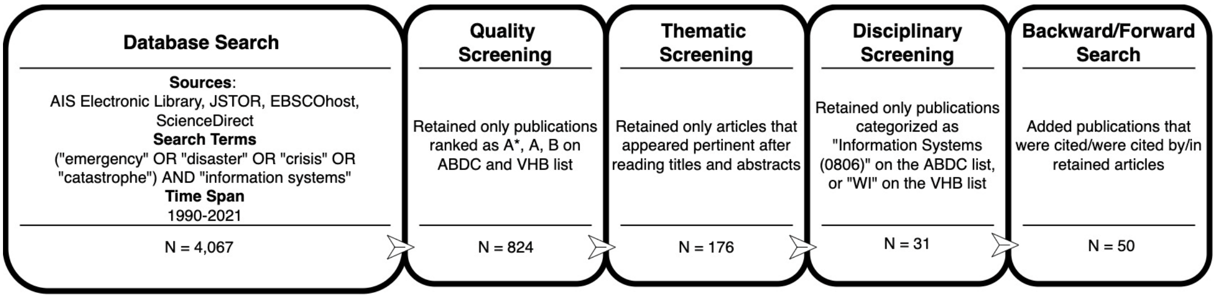

Figure 1. Paper selection process

For data coding, we started with extracting key information and topics from each paper such as the year of publication, EMIS type, disaster type, country, theoretical framing, study type, methodology, or stakeholders. From matching publication date with other relevant information (e.g., EMIS type), we derived the historical trend of EMIS (see section 4.1). In addition, during several rounds of reading the papers, we iteratively derived the EMIS functions from the papers and coded papers accordingly (see section 4.2). From this analysis, we identified gaps in EMIS literature and developed the agenda for future research.

4 Results

4.1 Historical trends in Emergency Management Information Systems

Researchers have long been interested in using information systems for emergency management. Figure 2 depicts a timeline of themes in EMIS research between 1990-2021. The first research strand focused on investigating *dedicated* and/or *propriety EMIS* build for and used by emergency responders such as those from fire fighting, paramedics, public authorities, or police. One of the seminal studies in this area in the IS discipline[1] was published by Turoff (1993) on a Distributed Group Support Systems—the so-called "Emergency Management Information System and Reference Index" which allowed messaging, conferencing, and data reporting in disasters. This paper followed several other studies on quite different technologies and tools that belong to the emergency management infrastructure such as data models, different proprietary emergency management software (e.g., decision support systems (DSS), knowledge management systems (KMS), or geographic information systems (GIS)), or the digital infrastructure used by emergency responders in general (e.g., Chen et al., 2008; Dorasamy et al., 2013; Jennex, 2004; Keenan and Jankowski, 2019; Leidner et al., 2009). EMIS researchers approached studying these systems by focusing on specific levels of EMIS use (Bonaretti and Piccoli, 2018) such as the database (Chen et al., 2013) or user-interface (McNab et al., 2011) but also on studying the entire infrastructure (e.g., Chen et al., 2008; Fedorowicz et al., 2018; Leidner et al., 2009).

Around 2007 *public social media* came into focus in studies on IS-enabled emergency response. In particular, seminal studies on the public's use of social media in emergency response were driven by the proliferation and ubiquity of internet access through smartphones to social media. These studies focused on how the public uses social media to respond to disasters—phenomena that are labeled as digital self-organization or digital voluntarism. The first studies in this area were not published in core IS outlets (Liu et al., 2008; Palen and Liu, 2007); the interest of IS researchers grew after 2010 with studies on the role of social media on public empowerment, in digital rumor propagation, and as boundary-spanning objects in disaster response (Ling et al., 2015; Oh et al., 2013; Tim et al., 2017; Vaast et al., 2017).

Around the same time, the popularization of wearable devices and sensors (i.e., the Internet of Things) increased opportunities for collecting emergency-related data. Mobile devices (e.g., smartphones) have multiple sensors such as gyroscopes, altimeters, GPS, or barometers. To use such potential of human sensing research started to create efficient methods to collect such data, for instance, by apps that support two-way information exchange between the public and responder organizations (e.g., Kaufhold et al., 2018) or integration of public social media content in professional emergency response activities (e.g., Ehnis and Bunker, 2020).

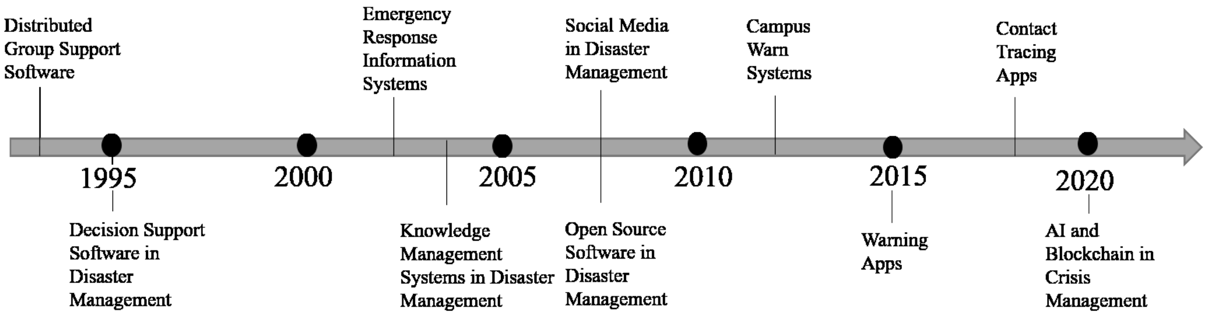

Figure 2. Timeline of information systems studied in disaster-related IS literature

In 2013, IS research began focusing on mobile-enabled disaster communication. More specifically, research focused on the use of mobile technology for campus emergencies, investigating compliance intention with SMS alerts (Han et al., 2015). As mobile-enabled warning systems, particularly warning

[1] Research on EMIS started earlier. See Belardo et al. (1983) or Wallace and Balogh (1985) for examples outside the IS discipline.

apps, became available to the general public, research focused on their effective use among the population (Fischer-Preßler et al., 2020; Kaufhold et al., 2018) and design guidelines for warning apps (Bonaretti and Fischer-Preßler, 2021). The spread of Covid-19 in 2019 gave momentum to research in emergency-related mobile technology, as the governments tried to use tracings apps, and Bluetooth technology, to cope with the pandemic. Contact-tracing apps are smartphone applications that enable tracing infection trails in the general population by tracking physical contacts among users. Researchers focused on the enduring question of *adoption* of a system in the context of mass acceptance of tracing apps (Trang et al., 2020). Moreover, tracing apps is the only technology in EMIS research studied in our analysis, that explicitly responds to cope with a transboundary disaster.

Future IS research may focus on AI systems and blockchain in emergency management. Early research began to discuss the potential of AI and blockchain in EM. In a literature review, Sun et al., (2020) identified 26 AI methods and 17 different application areas of AI to EM. IS scholars began to explore some of them, such as the use of conversational agents to facilitate knowledge sharing among emergency management agencies (Hofeditz et al., 2019; Sun et al., 2020). AI methods can support emergency response activities in the visualization and processing of large amounts of data stemming from satellites, unmanned vehicles, robots, and social media. Challenges lie, amongst others, in the size, variety, and also state-tracking of data and the capacity to process and use this data in a dynamic emergency event effectively. The development of efficient AI methods and research on effectively storing and processing emergency-related data through, for instance, cloud platforms will provide a fruitful research area. Also, the end-users from responder organizations will need training on the effective use of AI-based EMIS to implement them in their response activities. This may include new organizational roles that handle the adoption and application of new technological developments.

Furthermore, conference papers on blockchain in emergency management noted how some EM functions—i.e., dispatching and alerting, incident resource demand, and displaying geospatial data—can be handled similarly to smart contracts in a blockchain (Siemon et al., 2020). This may support interoperability of systems as well as timely deliberation processes within the responder network.

4.2 Functions of Emergency Management Information Systems

This section summarises EMIS research by its *practical concerns* and *emergency management goals* as well as the IT-supported *functions* to attain such goals. Based on our understanding of the historical overview, we broadly define EMIS as *socio-technical systems that enable storage, exchange, and access of emergency-related information to support professional emergency responders in the management of an emergency*. This broad definition of EMIS includes archetypal information systems and infrastructure typically involved in emergency response as described above as well as newer trends such as social media platforms, explained in more detail hereafter.

Scholars have stressed the practical orientation of EMIS research, which studies the "functionality requirements that the software needs for those planning and executing the emergency response management function" (Turoff et al., 2004, p. 3). For instance, GIS are needed for location and tracking, risk assessment systems for disaster risk identification, assessment, and monitoring, internet response grids and collaborative virtual work-spaces for disaster coordination, DSS and intelligent agent systems to support decision-making during a disaster as well as databases and knowledge management systems to serve as repositories of emergency-related knowledge. A single EMIS can incorporate several such functions. For instance, a DSS may have features that process geographical content in various types of spatial data sets.

In our literature review, we identified four overarching practical concerns and goals of EMIS use: understanding the situation, deciding and acting, collaboration among responders, and engaging with and outreach to the public. These goals are highly interrelated. For instance, deciding and acting is based on an understanding of the situation but also the collaboration between the responders. Table 2 gives an overview of the main concerns and goals, related functions, and examples of IS discussed in the EMIS literature.

Emergency management goal	IT-supported function	Type of system
Understanding the nature and scope of the disaster and attaining situation awareness.	Situation assessment: The collection, sharing, and presenting of on-site information.	Emergency management platform (Yang et al., 2012)
	Sense-making: View and process up-to-date disaster-related information to make sense of the disaster.	Social media (Eismann et al., 2016)
	Risk management: Support risk identification, assessment, and monitoring.	Decision support systems (Fertier et al., 2020)
Decision-making comprises deciding on the course of action to minimize harm.	Command and control: Clarify roles in the command chain dependent upon the type of disaster.	Collaborative database (Turoff et al., 2004)
	Decision support: Support determination, judgments, and courses of action during an emergency.	Decision support systems (Fertier et al., 2020)
	State-tracking: Provide a representation of the current status of different events and operations (e.g., the status of an event or casualties, resource allocation) and state changes related to the emergency.	Case management system (Devadoss et al., 2005)
	Human and material resource management: Provide information about the different organizations, the role of people, and resources involved in and available for emergency-related operations.	Central information management system (Yang et al., 2009), shared database (Turoff et al., 2004)
	Adaptation: Adjustment to respond to emergencies that vary in scale and scope.	Frugal information systems (Sakurai and Kokuryo, 2014)
Collaborating within the network of responders.	Interoperability: Technically support data exchange between different responder organizations.	Data models (Chen et al., 2013), ontologies (Chou et al., 2014)
	Communication: Support synchronous communication between responders on-site and in control rooms and across organizations.	ICT infrastructure (Leidner et al., 2009), social media (Ling et al., 2015)
	Common operating picture: Display relevant, operational information to more than one command to establish a common view.	Social media (Ehnis and Bunker, 2020)
Engaging with and *outreaching* to the community outside the professional response network.	Warning and recommending: Alert the affected population and give recommendations on protective action.	Warning systems (Han et al., 2015)
	Resource acquisition: Drawing on public ad hoc networks and resources.	Social media (Ling et al., 2015)

Table 1. Overview of the four functions of EMIS and their supporting activities

4.2.1 Understanding the disaster situation

A crucial function of EMIS is to help *understand* the situation notwithstanding severe time pressure and incomplete or uncertain information. By providing users with digital representations of the emergency and the related damages, EMIS enable them to perceive the event, its constituents, and its consequences. Planning and deciding on actions to be taken begins with *situation assessment.* Endsley's (1995) three-stage human cognitive model explains that *situation awareness* is achieved through the perception of environmental cues, comprehension of the events, and projecting their future states (Endsley, 1995). Drawing on Endsley's model (e.g., Bonaretti and Piccoli, 2018; Fischer-Preßler et al., 2020; Yang et al., 2012), scholars advocated for designing systems that are "situation-awareness oriented" and "dynamic" (Yang et al., 2012, p. 767) to maximize a user's perception and comprehension of relevant information to predict future states of the emergency. That entails, for instance, the ability to display on-site and current information (e.g., visual representations such as videos, maps, or pictures) (Yang et al., 2012).

Closely related to situation awareness but mainly studied in more noisy data sources such as social media use (in contrast to *professional* or *dedicated* EMIS) is the concept of *sense-making* defined as "the ongoing retrospective development of plausible images that rationalize what people are doing" (Weick et al., 2005 p. 409). Sense-making is the process of giving meaning to cues from the environment and occurs when a state is perceived to be different from an expected one. Since social media provide access to real-time disaster-related content, they enable the public to exchange information about the disaster and sensemaking (e.g., Eismann et al., 2018; Mirbabaie et al., 2020). For professional emergency response, social media might provide access to first-hand information that may be difficult to collect otherwise amid a disaster, thereby supporting situation assessment. However, such data may suffer quality issues or lead to information overload (Kaufhold et al., 2020) and at the same time, organizations struggle to incorporate social media data efficiently in their processes (Ehnis and Bunker, 2020).

Another crucial step towards understanding the emergency is *risk analysis, monitoring,* and *assessment* (e.g., Carver and Turoff, 2007; Leidner et al., 2009). Risk management is concerned with understanding the negative impact of threats for particular assets (e.g., building fragility assessment, road congestion risk) and response activities. Risk analysis, hence, contributes to situation awareness and the course of action to be taken, although the situation is "expected," rather than actual. IS literature discussed risk models which are implemented in EMIS and calculate the risks for people or material assets due to a threat. For instance, (Fertier et al., 2020) proposed a design for a DSS that integrates multiple data sources and predictive models to calculate risk exposure, such as how many victims could an incoming flood cause.

4.2.2 Decision-making during a disaster

The second emergency management goal is *deciding* on the course of *action* to manage the disaster. Disasters require complex decision-making in an uncertain environment. Related to the decision-making is the tracing of emergency-related *actions* and *resources*, that is, handling operations and activities.

Responder organizations' decisions and actions in emergencies are typically characterized by a top-down and heavily *regulated chain of command and control* (Karanasios et al., 2019). These structures and related roles are often mandated by laws, policies, and jurisdictional boundaries. There is an implicit assumption that the upper chain of command has a more complete overview of the emergency than individuals at the operational level and that decisions may culminate in negative consequences for the overall operation. Such vertical structure also ensures that conflicts arising in the EM process are handled timely (Turoff et al., 2004). To support centralizing and sharing information with the command and control rooms, EMIS infrastructures must be open to enable collecting data from on-site and sharing it with those in command (Carver and Turoff, 2007). EMIS that supports the command to act as a unity and create a shared vision can positively affect response activities (Leidner et al., 2009). However, centralization and several layers of coordination have been criticized because they do not necessarily improve organizational decision-making, since individuals will tend to overlook new information that is incongruent with prior knowledge (Thatcher et al., 2015).

Decision support is another crucial function of the EMIS infrastructure. Systems that support decision-making (i.e., DSS) typically combine several functions such as resource or risk management (Fertier et al., 2020), because these functions substantiate a decision and provide continued support once a decision has been made. For instance, a decision to evacuate people at risk needs to be supported by information on how many are at risk and need to be evacuated, are people nomadic, where do they find shelter, what means are available for evacuation, etc. (Carver and Turoff, 2007). In addition, since disasters always have a geographical reference, GIS are another crucial component of the EMIS infrastructure. GIS visualize situational information and inform decision-making (Currion et al., 2007). Nowadays, decision-making is also supported by machine learning models analyzing large data sets from various data sources (Sun et al., 2020), prioritizing relevant information for a respective user (Carver and Turoff, 2007), and presenting all the information in an easy to comprehend way so that users can make fast decisions (McNab et al., 2011).

In addition, *resource management*, that is, managing the types and levels of operational resources necessary to meet the demands of the situation and deploying them in a timely and orderly fashion is crucial. Once a disaster occurs, large amounts of resources such as technical equipment and human resources, are delivered by many response organizations to the affected area (Turoff et al., 2004). Collecting and sharing information and a thorough knowledge of available resources, both human and material, is essential. This includes a sound understanding of the involved responder organization, their roles, abilities, and weaknesses. Not only resource scarcity but also overabundance can easily occur if needs and demands are unclear and not communicated; and when a central control for resources is missing (Day et al., 2009). Hence, a central information management system (Yang et al., 2009) or shared database (Turoff et al., 2004) to track resources and match them with responders' needs is critical.

Another sub-function of EMIS is to *state-track* all the related activities of emergency response operations. In a highly dynamic disaster, information about the event, its impact, victims, and resources quickly become outdated before they can even be shared, making life-saving decisions challenging. Keeping up-to-date on the status of the event as additional information becomes available is paramount (Turoff et al., 2004). A system to record the number of positive cases can support tracking the spread of diseases (Devadoss and Pan, 2004).

Research unanimously agrees that only EMIS that are used regularly, will be used in emergency events, because in times of emergencies there is no time left to familiarize with a system (e.g., Allen et al., 2014; Turoff et al., 2004; Yang et al., 2012). Nevertheless, EMIS need to allow for a certain degree of *adaptability* to a given disaster situation. Any disaster is unique in terms of certain contextual traits such as time, type, location, or scale. In some cases, effective emergency management depends on principles and processes that assure adaptation to the situations, that is, flexibility and a smooth flow of information (Boin, 2019). Also, IS researchers agree with that view and seek technical approaches that allow adaptation to the situation. A frugal design, for instance, is characterized by universality, ubiquity, uniqueness, and unison. That means EMIS need to overcome information system incompatibilities, allow unconstrained information access by time and space, know responder's skills and location, and drive information consistency (Sakurai and Kokuryo, 2014).

4.2.3 Collaborating within the network of responders

The third EMIS goal is concerned with *collaboration* within and between organizations. Collaboration refers to all joint efforts of the disaster response network to cope with the situation. As responder organizations typically work with their own system, inter-organizational collaboration is often coupled with interoperability. *Interoperability* refers to the technical capability of the systems to exchange information. Most fundamental for interoperability is the exchange of data between the network of responders to overcome data impediments that create information gaps (Day et al., 2009). Shared ontologies and standards among responder organizations are necessary to attain interoperability and for sharing tactical, strategic, and operational information, are widely acknowledged to be crucial (e.g., Chen et al., 2013; Chou et al., 2014; Day et al., 2009) for coordinated and collaborative disaster response (Chen et al., 2013).

Another strand of EMIS research focuses on the characteristics of *disaster-related communication* within the network of responders. A disaster brings together a diversity of responders with different abilities, knowledge, and skills. Effective communication among these preexisting and ad hoc networks of public, private, and sometimes international responders is crucial to cope with disaster events and work towards a common goal. For instance, Pan et al. (2012) assert that the formal crisis response network is a social network that involves a mixture of cross-boundary socio-technical communications that needs to be adapted to the crisis at hand to manage it effectively. Communication often breaks down for a variety of reasons, which are rarely purely technical in nature (Bharosa et al., 2010). Rather the most debilitating communication barriers are cultural such as the lack of pre-existing communication routines, lack of trust between responder organizations, the predominance of organizational norms and rules, narrow, mono-disciplinary, or localized definitions of tasks, and what is important to know and divulge with others (e.g., Allen 2014, Bharosa et al., 2010).

Finally, EMIS can support collaboration by displaying a *common operating picture*, that is, a common view shared among all the involved responder organizations. Attaining a common operating picture is comparable to establishing inter-organizational situation awareness (Ehnis and Bunker, 2020). To digitally represent a common operating picture, EMIS shall enable “a manipulable visualization of what is happening and where resources are [and] that is open to all members of the emergency management team” (Carver and Turoff, 2007). However, it is difficult to attain a common operating picture by aggregating information from dispersed emergency response teams (Harnesk, 2013), particularly when organizations lack a sense of shared direction or common processes to involve stakeholders (Ehnis and Bunker 2020). In conclusion, the challenge of establishing a common operating picture is not only technical, but involves social factors such as flexibility and connectivity to incorporate spatially-related information and perspectives from the many involved responder organizations, information governance mechanism to guarantee information quality, resource management that constantly updates information on tools, and skilled personnel (Ehnis and Bunker, 2020).

4.2.4 Community engagement and outreach

The fourth area of EMIS research is concerned with *engaging* and *reaching out* to the community with a twofold goal. First, to alert communities about threats and to instruct the population about how to protect in response to the disaster. Second, to engage with the community to involve its members in disaster response activities and resource acquisition. To alert the population authorities must dispatch warnings. Public authorities have done so using channels such as SMS, warning apps (Fischer-Preßler et al., 2021b), or social media. No one channel is intrinsically best. For instance, warning apps enable dispatching accurate and information-rich warnings, but users need to download the app in the first place to receive warnings. That is why researchers focused on understanding factors contributing to intention to use warning apps (e.g., Trang et al., 2020) and what it means to use them effectively (Fischer-Preßler et al., 2020). For SMS, instead, research focused on drivers of compliance with mobile-enabled warnings (Han et al., 2015).

In addition, to *engage* with the community during disasters, the role of public social media came increasingly into the academic discourse (e.g., Eismann et al., 2016; Ling et al., 2015; Tim et al., 2017). Social media constitute a mediating digital platform connecting the online community to coordinate disaster-related activities (Ling et al., 2015; Tim et al., 2017), to self-organize, and to make sense of the situation (Eismann et al., 2016). Responder organizations, however, struggle to integrate social media data and volunteers in their response activities. It seems only natural that top-down hierarchically controlled organizations have problems integrating ad hoc grassroots volunteers, who spontaneously self-organize through social media, lack predefined roles and organizing principles. For a useful integration, many issues exist such as uncertainty about the volunteers’ skills or a coordinated assignment of tasks. Some researchers argued that social media irremediably splits crisis response into two distinct social networks with different capabilities: the *professional* disaster response network, and an *ad hoc* network of volunteers enabled by social media platforms (Harnesk, 2013).

5 Future research directions

We began our research to answer the question of *What research directions shall scholars pursue to address current challenges in EMIS research?* From our literature review, we identified key themes and related challenges in current EMIS research, their effects on studying EMIS, and give recommendations on how to overcome them (see Table 2).

Domain. Research in EMIS has been traditionally scattered across a variety of topics and interest groups. However, it also significantly linked to traditional IS concepts such as the design (e.g., Chen et al., 2008), evaluation (e.g., Fertier et al., 2020), adoption (e.g., Lee et al., 2011) of information systems, their integration into work routines (e.g., Allen et al., 2014) or effect on situation awareness and behavior (e.g., Ling et al., 2015), just to name a few. These research contributions are at the intersection of research on system types (e.g., DSS, KMS, social media) and one or more IS research streams such as interoperability issues, or adoption. The risk, however, is that scholars focusing on particular systems such as DSS, KMS, social media, fail to engage with EMIS-wide themes and, consequentially, to advance theory in EMIS. Such diversity might also create system-dependent research silos where EMIS core concepts in one silo remain invisible to scholars working in others. To avoid that, researchers shall identify a list of quality journals that will serve as a platform for developing the discourse in emergency management.

Context. Various definitions and typologies (e.g., natural, man-made, socio-technical, etc.) to cover different classes of disasters exist (e.g., Shaluf, 2007). However, EMIS research often overlooks the characteristics of different types of disasters and does not explicitly explain how certain characteristics of disasters translate into requirements of a system. In addition, as mentioned in the introduction some disasters show new characteristics, i.e., they are increasingly transboundary in nature (Quarantelli et al., 2018). However, our review identified only one EMIS—i.e., Covid-19 tracing app—to respond to such new threats. Defining context determines the generalizability of EMIS research across different types of disasters—e.,g., natural, man-made, socio-technical—and it is critical to understand how the characteristics of a disaster might affect the design of the system. For instance, how to design a system to track the state of slow-evolving disasters (e.g., drought, epidemic) versus one to track fast-evolving ones (e.g., terrorist attack, flash-flood)? Is it recommendable to integrate both functions in the same system? To answer similar questions in relation to context, researchers can conceptualize a set of environmental stressors (e.g., uncertainty, time-pressure, scope) to define context and types of emergencies more rigorously.

Methodology. A major methodological challenge when studying EMIS is the highly dynamic, volatile, and unpredictable nature of disasters. Studying EMIS in use is impractical because it is hard to predict when and where a system will be activated. Lab experiments, drills, training, or lower-scale emergencies are often more accessible to researchers but might fall short of capturing the scale and complexity of using an EMIS during an actual disaster. Larger scale deployments, instead, are mostly studied ex-post as case studies (e.g., Ling et al., 2015; Vaast et al., 2017), as field experiments and prototyping are probably "unaffordable experiments" (Sorensen, 1992) amid an actual disaster when human lives are at stake. Here, technologies such as virtual reality might address the key challenge of increasing the realism of lab experiments.

System types. EMIS researchers are interested in studying a broad array of different information systems such as social media, DSS, GIS, databases, or ICT in general that have the potential to affect emergency response (e.g., Chen et al., 2013; Fertier et al., 2020; Leidner et al., 2009; Ling et al., 2015). However, researchers' attention might prioritize studying systems practitioners are relatively uninterested in. For instance, social media analysis is rarely a major source of emergency-related information, although it has shown the potential to contribute relevant information. While data from social media platforms like Twitter captivate researchers, the growing popularity of open-source code for EMIS development offers new opportunities for easy-to-access data. The "public money, public code" mantra leads authorities throughout the world to make EMIS accessible to the public and, thus, to researchers too. Examples of open-source EMIS artifacts include Covid-19 tracing apps. For instance, the German and Italian Covid-19 tracing apps are entirely open-source and researchers can develop, test, and check the code for vulnerabilities.

Stakeholders and users. Research points to the increased visibility of technology-enabled volunteers and emergent groups to coordinate more effectively during disasters, or even to collaborate remotely with authorities (e.g., collecting and analyzing data). Social media, especially Twitter, are a major enabler of public participation. However, emergency managers sometimes doubt the relevance of social media for emergency management—voicing against the "tyranny of the tweet" (Palen and Anderson, 2016)—as the interpretability and accuracy of social media messages is often limited. Involving volunteers shifts the traditional hierarchical emergency management perspective into a bottom-up and emergent one (e.g., Ling et al., 2015; Tim et al., 2017). However, approaches to integrate digital volunteers into responder agencies' organizational structures are missing and more research is needed to develop solutions for effectively incorporating impromptu volunteers recruited through social media in professional responders' processes.

Area	**Challenges**	**Effect**	**Recommendation**
Domain	-What constitutes EMIS and disasters or emergencies is loosely defined -EMIS research is scattered across interest groups and topics	Fragmentation of EMIS research among IS topics	-To identify quality journals that EMIS scholars shall target -To foster interdisciplinary research
Context	-Disaster can have unparalleled characteristics -New threats such as transboundary crisis have special characteristics that need to be accounted for when designing EMIS	Fragmentation among research about different *types* of disasters, but lack of clarity about commonalities and differences among them leads to question the generalizability of the results from one type of disaster to another	To study how context influences system requirements
Methodo-logy	Disasters are unpredictable so data are often collected ex-post or during emergency exercises	-Abundance of case studies based on ex-post data analysis -Research falls short in contextualizing the study to a specific disaster	To explore new ways to increase the realism of laboratory experiments or scenario-based designs (e.g., using virtual reality)
System types	EMIS research studies a wide array of different information systems with their own users and interest groups	-There is a disconnect between artifacts that researchers focus on and those that practitioners need. -Systems that are relatively easy to draw data from (e.g., social media) are only marginally relevant for practitioners.	To diversify among systems for understanding, decision-making, and collaborating.
Stake-holder/ users	-Increased involvement of digital volunteers and emergent organizations -Responder organizations often struggle to use new technology	-Research focuses on public digital-enabled collective behavior; however, effective approaches to involve digital volunteers in emergency management are missing -Some EMIS may not be used because of their incompatibility with regulations or resistance to using them	-To develop approaches to onboard digital volunteers in emergency management -To study human/computer interaction for sustainable integration of EMIS in organizational processes
Theoretical pluralism	Theory is used opportunistically leading to theoretical fragmentation or weak theorizing	Knowledge is fragmented because it cannot build on shared theoretical paradigm	To develop contextualized theories or novel, unifying theories to foster knowledge accumulation
Definitions	Ambiguity in understanding of key terms (e.g., disaster,	Core concepts can be interpreted or called different	To develop taxonomies and consolidate definitions to

	emergency, user, or EMIS type)	by scholars working in different EMIS subfields	create shared language that is meaningful to practitioners and researchers alike

Table 2. Challenges in EMIS research and recommendations to overcome them

Some responder organizations still deal with very "basic" problems such as adoption. That makes rather challenging to develop research that makes both a strong theoretical and practical impact, as case study research and engaging with practitioners often means reminding them about lessons that IS scholars have learned. Structural, bureaucratic, and legal intricacies can make the adoption of technologies very complex, even more complex than in business contexts due to strict regulations. Hence, it is crucial to not only understand how technology can attain certain goals (e.g., interoperability), but also the regulations or general context that may hinder attaining such goals and develop technical solutions to overcome potential barriers. For future research, it is important to not only understand the process that facilitates adoption but also the antecedents of the wider context (i.e., regulations, laws, specificities of the responder organization) that may hinder the adoption of certain technologies.

Theoretical pluralism and practice orientation. To study the different activities and phenomena around EMIS, researchers applied a diverse set of theories. In fact, a key characteristic of this research stream is its focus on and application of a variety of theories such as sense-making (Mirbabaie and Zapatka, 2017), activity theory (Allen et al., 2014), or adoption theories (Lee et al., 2011). In addition, EMIS research lacks theoretical integration and a larger theoretical framework unifying that research stream. Some of these studies follow a positivist paradigm and test causal relationships, while other studies follow an interpretivist paradigm focusing on analyzing or explaining certain phenomena. All perspectives are legitimate and even necessary to understand the phenomena related to EMIS. However, theories following a positivist paradigm without incorporating the context may be used with caution or only when contextualized. For instance, if measuring intentions to use, researchers should be careful to take the measured value as a proxy for actual use behavior during a disaster. It is questionable whether an intention construct measured in a routine environment correlates with actual behavior during a disaster. Another key characteristic of EMIS research is that it constitutes a practice-driven area. Hence, not only theoretical fragmentation but also the lack of theory affects EMIS research. Some papers are without a clear theoretical commitment, or discretionally pick some concepts from a theory, or use theory loosely to frame the research question without contributing to the theory itself. While such research informs practitioners, it fails to contribute to theory development in EMIS research. In sum, we call for the development of contextualized theories in EMIS research and future theoretical contributions that unify that research stream.

Definitions. Alongside common theoretical paradigms, the development of shared definitions and key terms is another enabler of knowledge accumulation in EMIS research. Even relatively clear terms such as "disaster" or "emergency" can lend to jingle-jangle fallacies and hinder knowledge accumulation while generating redundant work. Confusion can arise because systems are used in uncoventional ways and do not clearly fit in traditional categories. In a review of knowledge management system in disaster management, for instance, Dorasamy et al. (2013) included social media because they support collaboration, even if it is unsual to characterzize social media as primarily KMS in IS research. Terms such as "case management system" can identify system that are rather different depending on whether the domain is publich health (e.g., Devadoss and Pan, 2004) or law enforcement. Here, the research opportunity is to consolidate key terms and definition while developing vocabulary that is meaningful to researchers and practitioners alike so that it facilitates applied research.

6 Limitations

EMIS design and application has significantly developed outside the IS research field; research in EMIS appears in domain-specific journals (e.g., Disasters, Journal of Homeland Security, Governance Information Quarterly) and interest and expert groups (e.g., Information Systems for Crisis Response and Management). Our quality criteria led to the exclusion of a variety of outlets that also provide fruitful insights into this literature stream but are outside the core IS discipline or were published in low-ranked outlets. While we focused in our review on studies from the IS field only, a literature review that aims for a comprehensive representation of the field should of course include outlets from other fields as well.

7 Conclusion

In the literature review presented above, we investigated previous IS research in EMIS, their functions for emergency response, and issues that are prevalent in EMIS research. In so doing, we provide a timeline of information systems that were studied in the context of disaster events and provide an overview of EMIS functions and use goals. Finally, we critically discuss issues in current IS-related EMIS research, explain their consequences for the EMIS research stream, and give recommendations for future research options. In so doing, we contribute to a growing and promising line of research that investigate a socially relevant and increasingly crucial domain. We do hope that our presented review pursues forward the EMIS research agenda.

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