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Advances in multi-agency disaster management: Key elements in disaster research

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Abstract Multi-agency disaster management requires collaboration among geographically distributed public and private organizations to enable a rapid and effective response to an unexpected event. Many disaster management systems often lack the capability to cope with the complexity and uncertainty. In this introduction to the special issues on advances in multi-agency disaster management we discuss the role of information, enterprise architecture, coordination and related human efforts aimed at improving multi-agency disaster management. The paper concludes that although there is a common body of knowledge, disaster management is still an under-developed area. There is a need to relate practice and theory by using human-centered approaches such that disaster management can realize its full potential.

Keywords Coordination · Enterprise architecture · Disaster management · Adaptivity

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1 Introduction

When disaster strikes, the complex task environment requires multiple organizations to transform from autonomous actors into interdependent decision-making teams. In order to ensure coherent coordination among the responding organizations, relevant information needs to be collected from multiple sources, verified for accuracy, and shared with appropriate responding organizations, all within a short time frame. During such situations, effective information sharing can prevent things from getting worse. The quality and timeliness of information shapes the effectiveness of emergency response efforts (Horan and Schooley 2007). Accurate and relevant information can be used to substantially reduce potential losses in many threatening situations (National Research Council 2007). A disaster is a continuously unfolding situation, marked by changes in urgency, scope, impact, the types of appropriate responders, and the responders' needs for information and communication. These dynamics add to the complexity and uncertainty of information sharing and coordination, while the ability to communicate and share information effectively becomes more crucial. Despite all research efforts, this paradoxical situation results in recurring failure of information sharing during exercises (ASE 2008; Chen et al. 2008). Unfortunately, recent response experiences and evaluations of disaster responders suggest that many disaster management systems often fall short of the capability to cope with the complexity and uncertainty.

The majority of current information systems for disaster response have been designed based on probable scenarios, and optimized for intra-organizational response and routine processes (Faraj and Xiao 2006). Therefore, such systems cannot adequately adapt to a constantly changing situation that often deviates widely from the design-time scenario.

Due to scarce resources and high uncertainty, it is infeasible to develop information systems for each and every conceivable disaster situation. Consequently, recent interdisciplinary research efforts have focused on developing the ability to facilitate the ever-changing information needs under the complex and unpredictable environments. Within the area of disaster management, a large number of technological innovations have recently emerged. Often these technologies have been developed in isolation of the other developments and have not been integrated into the daily routine operations of first responders, which might prevent effective use of the technologies during an emergency. Many cultural, organizational, jurisdictional and legal barriers also hamper or prevent necessary and proper coordination of relevant public and private organizations during unexpected events. Nevertheless, all these technologies and advances together provide the foundations of a unique platform that becomes a key to our ability to effectively respond to unpredictable and complex situations.

The empirical work in the field of disaster management remains limited. Especially, quantitative data collection remains scarce, which is not surprising as the number of disasters is limited. Moreover, the opportunity for collecting data first hand is restricted as it may be too dangerous or impede relief workers during the event of a disaster. This special issue of Information Systems Frontiers aims to compile the advances surrounding the emerging issues of multi-agency disaster management and contribute to the creation of a common body of knowledge in the multidisciplinary field of study. A number of studies presented in this special issue are based on empirical evidence and are useful for theory development. In the next sections, we discuss some of the major research problems and issues derived from the papers and provide an overview of those papers.

2 The complex and uncertain task environment

In contrast to relatively stable business environments, information and communications needs for disaster management are highly diverse and unpredictable, reflecting the multiple purposes for information and communication, the different activities, and information and communications needs that occur at different times and locations with respect to a disaster (National Research Council 2007). Responding to a disaster, either natural (e.g., floods and earthquakes) or human induced (e.g., terrorist attacks) is a complex process (Bigley and Roberts 2001) in terms of the number of actors, information systems and the interactions between actors and information systems. During the response process, multiple autonomous agencies form a response network and need to share information across the strategic, tactical and operational echelons. As a disaster evolves, the state and configuration of multiple elements in the response network change rapidly, indicating a high level of dynamics. The process of information sharing and coordination is further hampered by time pressure (Smith and Hayne 1997) and event uncertainty (Argote 1982), which lead to the unpredictability of information needs and flows (Longstaff 2005). Moreover, the standard administrative approach to solving complex problems has been to hierarchically organize work involving multiple agents and tasks (Simon 1996). Hierarchy is used to establish control, specify tasks, allocate responsibilities and reporting procedures, and presumably gain reliability and efficiency in workflow. This approach works reasonably well in routine circumstances when there is time to plan actions, train personnel, identify problems and correct mistakes. Under the urgent, dynamic conditions of disaster, however, such procedures almost always fail (Comfort and Kapucu 2006). Under cumulative stress, hierarchical organizations tend to break down, and personnel are hindered by a lack of information, constraints on innovation and an inability to shift resources and action to meet new demands quickly (Comfort 1999). In extreme environments, we need to acknowledge that not all relevant information is known, and that previously known conditions may be in a state of flux.

3 Timing is everything

If information is delivered too late, it may fail to prevent damages or losses, while if too early, it may be neglected. In addition, too much information results in a huge information overload. For example, the providing of a map displayed on the visor of a firefighter can result in a distraction from the real situation. For the firefighter it may results in a huge information overload and the inability to concentrate on the tasks at hand. Alternatively, not having a map might result in the firefighter losing his or her way. Accurate information should be given to fire fighters during a briefing, supplemented by on-demand requests for information based on the fire fighter's specific circumstances and problems.

During disasters the need for information changes continuously. There are various phases in disaster management that demand specific information. A typical disaster management cycle includes mitigation, preparedness, response, and recovery (Board on Natural Disasters National Research Council 1999). Figure 1 shows an example of a crises life cycle starting with prevention and ending with evaluation. On the x-axis the time line is shown and on the y-axis the impact is shown. Early signals should be

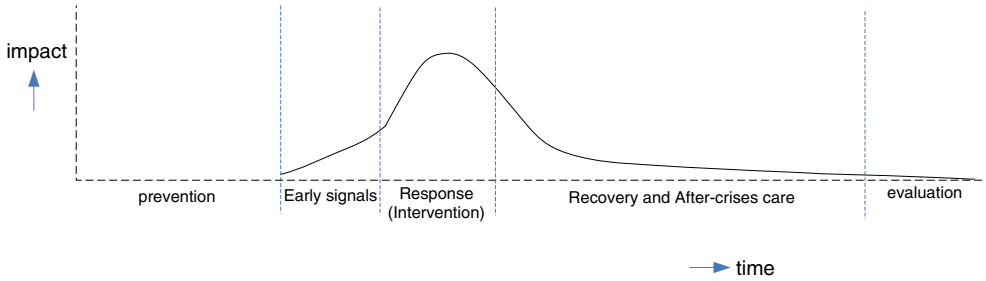

Fig. 1 Phases in disaster management

combined to create a common operational picture of the problem at hand.

The various phases require different types of processes and information. The various phases combined with the many uncertainties result in the need for adaptive architectures. Much of the current research is focused on the intervention phase, which might look the most attractive at first glance. The other phases might be equally important, as prevention can avoid the disaster, early signals might result in an earlier detection and more effective approach resulting in less damage. The after-disaster phase can help people to recover quickly by reducing conflicts and allocating resources more efficiently.

4 Enterprise architecture as a foundation

Traditionally, agencies involved in disaster management are organized vertically around departments. This structure reflects their single-agency process description during non-disaster circumstances. It is only during disasters that cross-agency processes need to be initiated and supported. Cross-agency processes can be created only by integrated information systems delivering timely and accurate information, and supporting inter-organizational processes. The existence of isolated, overlapping in function and content, highly fragmented, and unrelated computerized applications within individual agencies has resulted in a major interoperability problem and has led to 'isolated islands of technology' in information systems.

Opportunities for joint-development, pooling of resources, coordination of efforts and exchange of information are often neglected due to the lack of overview. Responders are often unaware of the efforts within their own organization or field, let alone the development in other fields. Enterprise architecture (EA) defines and interrelates data, hardware, software, and communications resources, as well as the supporting organization required to maintain the overall physical structure required by the architecture (Richardson et al. 1990). EA can be used to guide decision-making and as guidance for development in the existing situation and ensuring interoperability. Many definitions of information architecture can be found in the literature, however as yet, there is no generally accepted definition (Ross 2003). Unfortunately, very little is known about how EA looks or should be used for disaster management. Existing EA frameworks are of necessity quite general, so as to be relevant to a wide range organizational situation. As a result, they are not well adapted to the unique situation of crises and disaster management.

In addition, EAs should be understandable by all stakeholders in order be used effectively. The creation of a shared vision, communication among stakeholders and evaluation of the impact seem to be crucial aspects. Furthermore, EA should contain standards to enable interoperability. In general, the following aspects should be part of the EA:

- Providing an overview of elements at an appropriate level of abstraction
- Embedding of technology
- Ensuring coherence among elements at various architectural layers
- Enabling communication among stakeholders
- Covering data standards and semantic description of objects to enable interoperability

Ultimately, EA should be able to align crises management and technology. Although EA has not been understood and used very well in the context of disaster management, it might be a critical necessity for facilitating an effective response.

5 The need for extending coordination theory

Coordination theory is often claimed to be at the center organization theory (Faraj and Xiao 2006). The limited capacity and resources, the problems caused by the division of tasks and labor, and the corresponding mechanisms needed to overcome the problems form the core of *organizational design* (Galbraith 1977). Although coordination has attracted a great deal of attention, there are several issues that require more research. For example, the coordination of commitments based on *relationships* has received little attention within this field (Winograd and Flores 1987). Winograd and Flores (1987) found that most human coordination occurs in a basic cycle consisting of requesting, making and fulfilling commitments between

people. Consequently, the importance of the ICT lies in facilitating this kind of coordination activities rather than in information processing. This view might prevent situations in which the sharing and coordination of information fails due to lack of clarity about what information is needed by whom and when, and who is responsible for providing the information.

Traditional models of coordination are also inadequate for volatile and dynamic situations (Faraj and Xiao 2006). Information needs and the appropriate coordination mechanism for the needs may vary with changes in the disaster situation. Therefore, there is a need to develop flexible coordination mechanisms that can be easily customized for the specific situation and provide better supports for improvised responses (Chen et al. 2008; Mendonca 2007). Such mechanism will ensure that necessary information is shared, creative solutions are found, and all participants are aware of each others' position and difficulties. This also gives a rise to research in the network centric operation (NCO). Hierarchical control is often viewed as a necessity for dealing with disaster, as there is simply no time for negotiation structure and other time-consuming actions. This does not mean that more peer-to-peer approaches are not suitable, as there is a need for ensuring adaptability in the situation, empowerment of teams and decentralized decision-making, as the first responders on the scene are often in the best position to assess the complex situation. The questions remain whether hierarchical and peer-to-peer coordination structures are fundamentally incompatible or can they be combined, and if they can, to what extent? We argue that they should be viewed as complimentary concepts. In this way, researchers can explore novel approaches in which the best of both worlds can be combined.

Disaster management is underpinned by reciprocity, mutual trust and willingness to share information among organizations. These types of interactions should occur not only at the top of the organizations making decisions jointly, but also at lower levels. Boundary spanners are organizational members who link their organizations with others (Thompson 1967). They should be able to discern relevant information for the related organizations and make decisions concerning the distribution of gathered information. Information orchestrators (Bharosa et al. 2008) are boundary spanners who are institutionalized to enable information exchange among organizations. There are various terms for this type of orchestrators, including "Network Administrative Organizations" (NAO) in the public administration literature (Milward and Provan 1995), "process orchestrations" (Janssen et al. 2006) and "network orchestrations" in innovation network studies (Dhanaraj and Parkhe 2006). A typical example for an information orchestrator is the emergency control room (ECR) which is equipped with all kinds of ICTs to collect data from first responder and in turn share information. Often ECRs are operated by persons not familiar with the needs of decision-makers and first-responders in the situation at hand, which can easily result in failure to share crucial information. In spite of their crucial role, little is known about how boundary spanners influence cross-agency coordination and their effectiveness for disaster management success.

Taken together, the above research suggests that knowledge of the situation, the information sharing needs, and why some information needs to be shared with whom is important for selecting appropriate coordination mechanisms. A cross-organizational coordination mechanism can be achieved by designing and then imposing an end-to-end coordination process over multiple agencies. Alternatively, shared infrastructure and mechanism for cross-organizational coordination can be developed first, independently of the coordination problems, then used to solve any coordination problem that emerges. In the recent past, the latter seems to be the preferred way of developing a cross-agency coordination mechanism. The bottom line is that various approaches are possible in the disaster management context, but which approach should be chosen in which circumstances is unclear.

6 Focus on human-centric approaches

Crises management is centered around humans, including first responders and decisions-makers. Equally important are persons outside these responding organizations, such as civilians, who might help or observe something that is crucial. In fact, civilians are often the actual "first responders" as a result of being caught up in or near the location of a disaster. One general recurring element that is found in almost all papers this field is the need to focus on human action, whether this is empowerment of first responders, supporting decision-makers, or helping victims and volunteers. The human-centered approaches allow researchers to assess the inter-organizational communication links, processes, and information hand-offs that concern the victim's objectives and activities. The Network-centric Operations approach acknowledges the need to empower humans (i.e., relief workers) during disaster management. The military haves experiences with NCOs aimed at broadly sharing situation awareness of events using a Joint Operational Picture (Alberts et al. 2002). Four basic propositions of an NCO and a set of governing principles for a network-centric force have been identified by the Department of Defence (Alberts and Hayes 2007). The tenets of network-centric warfare are:

- A robustly networked force improves information sharing

- Information sharing and collaboration enhance the quality of information and shared situational awareness
- Shared situational awareness enables self-synchronization, and enhances sustainability and speed of command
- These, in turn, dramatically increase mission effectiveness

These propositions provide high-level strategies for improving information sharing and coordination. However, there is little understanding of how to design disaster management systems and how they can be well attuned to the information needs of first responders, citizens, and victims. More research into human-centric approaches is necessary. In a similar vein, crises management systems should be conceptualized as complex socio-technical entities, and information systems as by-products of interacting technical and social aspects (e.g. Rockart and Scott Morton 1984). Unfortunately, all too often, technology is considered in isolation, which ultimately results in the lack of adoption and the waste or resources. The systems are inseparable from the organizational and institutional context within which they are situated and used, as well as being the product of path-dependent histories (Yang et al. 2009). The basic idea of socio-technical design is to ensure that both technical and human factors are given equal weight in the design process (Mumford 2006). The key implication of the socio-technical approach is that only by considering the interdependencies among the various subsystems, technology and social, we can optimize the performance of the whole system (Bostrom and Heinen 1977). Systems should be more directly oriented toward their human users' needs, as opposed to be built around silos of organizational information requirements developed on an agency-by-agency basis. Socio-technical design approachs can bridge the gap between the many technological advances and the relationships among the crises management organizations and personnel.

7 The need for evaluation metrics

Evaluation is a thorny problem in the field of IS research (Smithson and Hirschheim 1998), especially because systems are complex socio-technical entities. Evaluation is interwoven with the organizational context of disaster management and is dependent on the interaction between the social and technical aspects. If one part fails, the whole systems can suffer from the failure. Evaluation is often viewed as an external judgment treated in isolation of the crises management, a view that has been criticized in terms of internal validity. Crises management exercises show that despite good systems and information quality, the information sharing is still be considered as an important problem (ASE 2008). A danger is to put excessive emphasis on easy-to-measure aspects and neglecting organizational and social processes. An evaluation requires often a deep understanding of the crises and the complex interactions and should embrace the uncertainties and complex dependencies. Following other authors (e.g. Smithson and Hirschheim 1998), we argue here for more interpretive methodologies for valuation which take into account the experiences and organizational realities and focus on meaning given by stakeholder groups.

8 Papers overview

We have received a total of twenty three manuscripts for this special issue. After two rounds of reviews, five papers were selected for this special issue. These five papers cover a variety of aspects in the field of interagency disaster management.

The first paper, "Collaborative Systems Development in Disaster Relief: The Impact of Multi-Level Governance," by Edgar Maldonado, Carleen Maitland, and Andrea Tapia, examines the implications of multi-level governance in a disaster information systems development process. Adopting a case study approach and by integrating political science and information systems theories, the paper analyzes the system development effort undertaken by a multi-organizational/multi-level coordination body in a Central American country. The findings emphasize the impact of resource flow from higher to lower level organizations and coercion by higher levels of authority.

The second paper, by Dickson Chiu and his colleagues is on "Alert Based Disaster Notification and Resource Allocation". The system they present is built on a unified Web services platform that supports timely interactions among various parties via notification and monitoring, resource enquiry and allocation, and the mobility of information. The applicability of the proposed systems is also illustrated by an epidemic outbreak scenario, which can help various stakeholders realize the advantages of the systems.

The third paper, "Challenges and Obstacles in Sharing and Coordinating Information during Multi-agency Disaster Response: Propositions from field exercises," by Nitesh Bharosa and his colleagues, reports on a series of disaster response exercises in which multiple responder agencies try to mitigate a disastrous event. Adopting both qualitative and quantitative analyses techniques, the paper identifies a list of obstacles to effective multi-agency disaster management, including the absence of incentive for information sharing, lack of understanding of others' information needs, and a low level of systems usability. The paper presents a set of propositions formulated from the findings.

In the fourth paper, "Information Intermediaries for Emergency Preparedness and Response: A Case Study

from Public Health," Minu Ipe, Raghu Santanam, and Ajay Vinze identify the responsibilities and challenges that information intermediaries in the public healthcare industry need to deal with in deploying a public health emergency preparedness system. The authors also discuss various issues influencing the situation, including stakeholder participation and commitment, inter-organizational collaboration, and organizational structure and resources. They present a set of propositions focused on trust, coordination, information sharing and incentive alignment, all in relation to the role of information intermediaries.

Finally, the paper "Reinvention of Interorganizational Systems: A Case Analysis of the Diffusion of a Bio-terror Surveillance System," by Jane Fedorowicz and Janis Gogan seeks ways to reinvent innovative inter-organizational systems to enhance the acceptance and further diffusion of an IS innovation, as well as the processes affecting such a reinvention. Building on the innovation diffusion theory, this paper analyzes the process of post-adoption modification of an inter-organizational system designed to detect bio-terror attacks and identify acute disease outbreaks.

9 Conclusions

We typically expect advances in technology to offer a completely new approach to crises management. Despite all efforts, however, there is a huge gap between theory and practice that needs to be bridged. Design research is especially necessary for situations in which the newest technologies are combined with the daily practice. This approach should be centered around human-centric systems architecture.

This special issue suggests that many research directions are open, and the current research addresses only the tip of the iceberg. We opt for more research in multi-agency disaster management, especially in the field of information sharing and provisioning, enterprise architecture, coordination and human-centric approaches. In addition, it is necessary to develop evaluation metrics that go beyond traditional measures like systems quality, information quality and service quality.

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