Reconsidering information management roles and capabilities in disaster response decision-making units

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ABSTRACT

When disaster strikes, the emerging task environment requires relief agencies to transform from autonomous mono-disciplinary organizations into interdependent multidisciplinary decision-making units. Evaluation studies reveal that adaptation of information management to the changing task environment is difficult resulting in poor information quality, indicating information was incorrect, outdated or even unavailable to relief workers. In this paper, we adopt a theory-driven approach to develop a set of information management roles and dynamic capabilities for disaster management. Building on the principles of advance structuring and dynamic adjustment, we develop a set of roles and capabilities, which we illustrate and extend using two field studies in the Netherlands. By studying regional relief workers in action, we found that in tactical disaster response decision-making units, several information management roles are not addressed and that information managers are preoccupied with information gathering and reporting, whereas information quality assurance is not on the agenda.

Keywords

Information architecture, information management, adaptivity, roles, dynamic capabilities

INTRODUCTION

The motivation for this research stems from multiple evaluation reports on multi-agency disaster response efforts such as the 2004 Asian tsunami (Samarajiva, 2005), Hurricane Katrina (Townsend et al, 2006) and the large fire at Schiphol in the Netherlands (Van Vollehoven et al, 2006). These reports present alarming evidence of poor information sharing and management, resulting in poor information quality for relief workers. For instance in the response to the 2004 Tsunami, "mostly, the information was incomplete, yet conclusions must be drawn immediately" (Samarajiva, 2005) and in the response to hurricane Katrina, "the federal government lacked the timely, accurate, and relevant ground-truth information necessary to evaluate which critical infrastructures were damaged, inoperative, or both" (Townsend et al, 2006). Another example can be found in the response to major fire at Shiphol Detention Unit, where the Dutch firefighters rushing to the area had received inconsistent information about the available gates to the area and were delayed in finding the right gate providing them access to the area (Van Vollehoven et al, 2006).

During disasters, sharing and dissemination of information is both critical and problematic (Manoj & Baker, 2007), yet for relief workers, high information quality is critical (Fisher & Kingma, 2001). This because the activities of relief workers are information intensive (De Bruijn, 2006) and their effectiveness largely depends on the information they have available (Davenport & Prusak, 1998). Scholars have identified multiple contingencies that complicate the information sharing process, including complexity (Bigley & Roberts, 2001), dynamics (Rudolph & Repenning, 2002) uncertainty (Argote, 1982) and interdependency (Granot, 1997).

Following Comfort and Kapucu (2006) who state that adaptivity is essential for dealing with such contingency factors, we argue that the key for assuring information quality during disaster response lies in the adaptivity of the multi-agency information management architecture. Adaptivity refers to collective system property different from concepts such as agility and flexibility, which indicate the possibilities for adapting from the one state to the other. More specifically, we define adaptivity as the degree to which a decision-making unit has a variety of dynamic capabilities and the speed at which they can be activated, to match information demand and supply. We treat adaptivity as a multi-dimensional concept, indicating that arrangements for adaptive information management can be found on multiple layers of the information architecture, including the institutional, actor, process, informational and technology layers of disaster management systems. For instance, on the technology layer, information technology have acted as enabling and integrating tools for survival and growth in rapidly changing environments (Johannessen & Olaisen, 1993). Complementing previous work, this research focuses on

the roles and capabilities required to ensure adaptive information management in decision-making units on the strategic and tactical echelons.

The aim of this paper is to identify a set of roles and dynamic capabilities required for adaptive information management and create a better understanding of the various architecture arrangements and trade-offs necessary to ensure information quality. This paper proceeds with a discussion on the theoretical background by exploring information management, requirements for information management, specificities of information management in disaster situations (multi-organizations context where hierarchy is not the solution anymore), dynamic capability theory, needs for adaptivity and study about information management problem. The second part of this article presents the conclusion of two field studies and especially the identifies lack of capabilities and roles. Finally, in the conclusion section we propose a minimal sub-set of roles in order to ensure a basic sub-set of required capabilities.

THEORETICAL BACKGROUND

Previous work on information management

Information management is a relatively well-studied subject in the information systems domain and is defined from various angles. Consequently, scholars have proposed multiple information management frameworks (e.g., Checkland & Holwell, 1993; Choo, Deltor, Bergeron, & Heaton, 2006; Rowley, 1998). For instance, Choo (1998) defines information management as "a cycle of processes that support the organization's learning activities: identifying information needs, acquiring information, organizing and storing information, developing information products and services, distributing information, and using information". Previous work often treats information management as a predictable, intra-organizational process (e.g., Choo, 2000; Kirk, 1999). However, during disaster response, information management becomes a multi-agency process and adaptivity becomes a key requirement for dealing with dynamics and uncertainty. The need for adaptivity is discussed next.

Information management in extreme conditions: the need for adaptation capabilities

In contrast to relatively stable business environments, information and communications needs for disaster management are highly diverse in nature, reflecting the multiple purposes for information and communication and the different activities and information and communications requirements 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, earthquakes) or human induced (e.g., terrorist attacks) is a more complex process (Bigley & 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 on the strategic, tactical and operational echelons. As a disaster evolves, the state and configuration of multiple elements in the response network changes rapidly, indicating a high level of dynamics. The process of information sharing and coordination is further hampered by time pressure (Smith & Hayne, 1997) and event uncertainty (Argote, 1982). Moreover, uncertainty often leads to the unpredictability of information needs and flows (Longstaff, 2005).

In such environments, the standard administrative approach to solving complex problems has been to organize work involving multiple agents and tasks hierarchically (Simon, 1996). Organizational challenges are prevalent in disaster response, especially when groups that are accustomed to hierarchy and hierarchical (centralized) decision making must suddenly work in a flatter, more dynamic, ad-hoc organization that emerges during post-disaster relief efforts (Manoj & Baker, 2007). Hierarchy is used to establish control, specify tasks, allocate responsibilities and reporting procedures, and presumably gain reliability and efficiency in workflow. This approach works well in routine circumstances when there is time to plan actions, train personnel, identify problems and correct mistakes. However, under the urgent, dynamic conditions of disaster, such procedures almost always fail (Comfort & 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. When the assumptions about the environment turn unpredictable, the main modes of information seeking change from conditioned viewing and searching to undirected viewing and enacting (Choo, 2000). Each of the transformations mentioned stress the collective information architecture supporting information sharing and coordination between multiple agencies even more, underlying the need for adaptation of the information supply to the demand as the situation develops. Adaptivity, being a multi-dimensional concept, can be designed on various levels of an information architecture, including the organizational, process, informational and technical layers. Taking a socio-technical perspective (Bostrom & Heinen, 1977b) on information systems for

disaster management, we argue that the development of information management roles and dynamic capabilities are necessary to improve adaptivity. Roles and capabilities as found in literature are discussed next.

Roles and dynamic capabilities

An essential part of information architectures is the definition of roles. We view information management as a set of interacting processes that are executed via roles. The fulfillment of roles requires capabilities, which in turn require specific information technology functionalities. It is often argued that an organization can be described by a number of roles (Kambil & Short, 1994; Kendall, 1998). Roles are organization and technology independent and can be transferred to other situation. Kambil and Short (1994) describe a role as "*a distinct, technology independent, value-added activities undertaken by firms or individuals*". The bottom line of their description is that three characteristics of roles are important. First, roles should independent of implementations. Second, they should be long lasting instead of being short term, temporarily occurrences. Finally, they should create some value as otherwise they would not be necessary. Executing a role requires business processes, capabilities, supporting technology and knowledge and skills. Roles are aimed at achieving a certain goal to create value. Kendall (1998) describes a role as "*a position and a set of responsibilities within an overall structure of system*". One can find roles in various domains. For instance, Wiederhold and Genesereth (1997) describe roles for mediating services. Janssen and Sol (2000) describe roles of intermediaries between supply and demand and specify these using an object-orientated approach. Pan et al (2005) describe the roles of organizations involved in the SARS outbreak in an appendix of their paper. Although their focus is not on roles and it is not clear what a role is, this was used as input for defining our roles. Typically, one or more processes are used to execute roles and a role needs one or more dynamic capabilities.

The dynamic capability theory (DCT) describes the ability of organizations to adapt to a changing environment (Teece, Pisano, & Shuen, 1997). While the resource-based view (Barney, 1991) considers resources as static, dynamic capabilities look at reconfiguration of roles to adapt to the changing circumstances . In disaster management, the situation keeps on changing and consequently there is a high need for dynamic capabilities. Dynamic capabilities help organizations to change their resource configurations in order to cope with a changing environment. Teece et al. (1997) define dynamic capabilities as "*the ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments*". Dynamic capabilities are the unique processes to integrate, reconfigure, gain and release resources (Eisenhardt & Martin, 2000).

Scholars have identified dynamic capabilities in various domains. Teece et al. (1997) have suggested three main types of organizational capabilities for creating strategic advantage in business enviroments: 1) coordination and integration, 2) learning and 3) reconfiguring and transformation. Feeny and Willcocks (1998) have identified nine core capabilities in the field of business process outsourcing and categorized them in the following three groups: 1) business and IT vision, 2) design of IT architecture and 3) delivery of services. Pavlou & El Sawy (2004) propose reconfiguration as the deployment process to achieve new configuration, and four enabling processes to facilitate reconfiguration: (a) sensing the environment; (b) learning; (c) coordinating activities, and (d) integrating resources. Klievink and Janssen (2009) have identified four groups of essential capabilities for e-government transformation: stakeholder, technology, transformation and service delivery. For disaster management such a categorization does not exist. In the next section, we propose such a classification based on principles from coordination theory.

Coordination theory: two principles for developing dynamic capabilities

For disaster management, the information flow between supply and demand continuously needs to adapt to the changing environment. Gosain et al (2005) suggest two principles based on coordination theory for achieving adaptivity: advance structuring and dynamic adjustment. Advance structuring refers to the beforehand structuring of inter-organizational information flows and interconnected processes, such that agencies can reduce the effort involved in adjusting to the changing task environment during the disaster. Hence, in the context of disaster management, advance structuring requires arrangements to be implemented in the disaster prevention, detection and mitigation phases. Advance structuring requires preemptive and protective capabilities for structuring inter organizational information flows, for instance by reducing task interdependence through loose coupling (Tan & Sia, 2006), or mitigating resource dependency by diversifying resource allocations (i.e., creating alternative information sources).

On the other hand, dynamic adjustment refers to IT-supported learning and adaptation of information flows and processes, such that organizations can effectively and quickly reconfigure a set of inter-organizational processes appropriate for a changed task environment. Dynamic adjustment, involves real time reconfiguration of inter-organizational information sharing processes for a changed disaster environment. Renewing competences and reconfiguring organizational resources are two key aspects to achieve new forms of coordinating information. The primary theoretical basis for dynamic adjustment is learning based sense and adapt paradigm (Haeckel,

1995). Sensing for adaptation is important from the dynamic capabilities view as it represents an agencies ability to sense and acquire real-time information about external, changing environments and to adjust its actions accordingly. Both the advanced structuring and dynamic adjustment principles are visualized in figure 1.

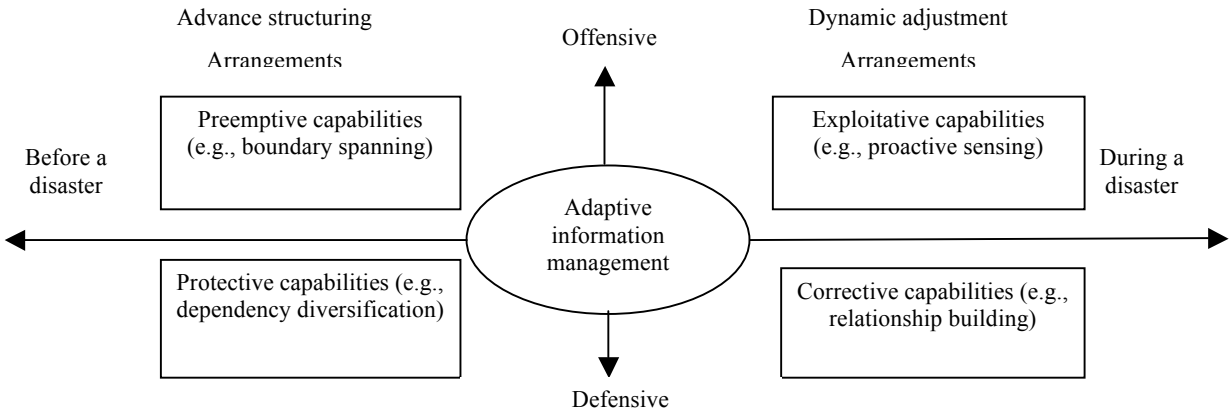

Figure 1: Adaptive information management

According to figure 1, advance structuring and dynamic adjustment require a set of capabilities for assuring adaptive information sharing and coordination. These capabilities have not been studied in detail yet, especially in the context of disaster management. As mentioned in the introduction, we aim to identify and specify such the capabilities necessary for adaptive information management. Having identified the type capabilities, the next section is on the illustration and specification of these capabilities in the disaster management context.

RESULTS FROM FIELD STUDIES

Throughout 2008, we studied two cases on disaster response drills in different geographical regions in the Netherlands. Both field study cases, Rotterdam and Gelderland, entailed a series of disaster response drills on the strategic and tactical echelons. The fieldwork is part of a longitudinal research on information management and quality (Bharosa, Appelman, & de Bruijn, 2007; Bharosa, Lee, & Janssen, 2009). The purpose of our fieldwork was to understand how information is managed in decision-making units and how information quality problems are countered. This can help us to address the question as to how relief agencies can better utilize information management roles and dynamic capabilities to counter information quality issues.

Prior to the disaster response drills, we interviewed a number of information architects (15 for Rotterdam, 5 for Gelderland) on the information sharing process, roles and capabilities to ensure information quality. The one and a half hour interviews were semi-structured and pre-tested with three experts. After each interview, we returned an interview transcript to each respondent in order to validate our conclusions. After validation, we coded and analyzed the transcripts using Atlas.ti for advance qualitative analysis. After the interviews, we observed multiple exercises (8 exercises in Rotterdam, 2 exercises in Gelderland) based on an observation protocols constructed for studying the information sharing process, roles, capabilities and information/system quality issues. We pre-tested the observation protocol in previous field observations (source hidden for anonymity). The interview, observation and coding protocols are available upon request. The following table lists some of our main findings across both cases.

Proposed capability	**Type of capability**	**Explanation**	**Rotterdam**	**Gelderland**
Ability to create shared situational overviews	Preemptive	Generation of shared situational reports and dynamic plots of the hazard area. The data found needs to be summarized to an appropriate level of abstraction	This capability is fully available to the information managers who can generate both reports and plots	This capability is partially available to the information managers who can generate situation reports but not the plots
Ability to share situational overviews	Exploitative	Sharing of shared situational overview with team members using shared digital maps which portray location and	This capability is only partially available, for this team members need	This capability is fully available as information managers use

		meta-information	to look at the laptop screen of the information manager	beamers to project situation reports
Ability to understand information needs across organizational boundaries	Preemptive	Someone in the decision making unit who understand various agency's processes and can cluster and integrate information demand and supply across agencies	In both cases, information managers (police officers with a special training) are used as boundary spanners between agencies. However, we do see a tendency to focus on the processes and information needs of the own organization (police)	
Ability to consult and develop information libraries (history and event management)	Preemptive and protective	Define a library containing information based on the experience from previous disasters together with some field experts. The next time we encounter A (or a circumstance similar to A), we will be prepared, and more likely to react adequately	A list of large public spaces for keeping evacuees was available, but this was hard to find and contained outdated information	Not available
Ability to access private/external information on demand	Corrective	Rapid composition of new web services in order to accommodate unprecedented information needs such as external/private information on stored chemicals	Not available	Not available
Ability to enrich information	Corrective	For instance completing and updating of situation reports	Not available	Not available
Ability to anticipate information needs	Exploitative	Extrapolation and prediction of the event variables in order to anticipate information needs and which reaction would be appropriate	Not available	This capability is partially available for flood related information (one agency can simulate the flood)
Ability to consult expert panels	Preemptive and corrective	Keep and maintain a list of experts on specific information classes and call upon their services when needed (e.g., errors in data or expectations need to be identified)	Not available	Not available
Ability to reuse information for various processes	Preemptive and corrective	Information on for instance the location, weather and local risk should be reused by agencies as much as possible to avoid inconsistencies	Not available	Not available
Ability to automatically filter information to the task at hand	Protective	The use of software functionalities to select useful or interesting information for the user among a large amount of information can avoid information overload	Not available	Not available
Ability to label information	Protective	Tagging or insertion of meta information can avoid the use of outdated information and the sharing inconsistent information	This capability is partially available, the information manager can label new information	Not available

Table 1: Cross-case findings

Findings from interviews

The interviews reveal how various information architects from different agencies have different opinions and knowledge on several information quality requirements and measures. Generally, the information architects felt that currently creating semantic and syntactic interoperability across agency databases is priority whereas information quality is a future concern. Moreover, information quality is a hard to measure concept from the information architects perspective and is therefore difficult to decide on measures and arrangements for dealing the information quality issues.

Almost all the respondents mention two main roles for information management on the strategic and tactical echelons: the information manager and the plotter. In the current information architecture of both field cases, multiple information manager and plotters (or situation visualizers) are defined to assist decision-making units. Both roles are enabled via information technology capabilities such as messaging and visualization. More than half of the respondents mentioned the role of the information manager in ensuring information quality for relief workers. Usually, the role of information manager is fulfilled by a police official on both the tactical and strategic echelons. This information manager should act as a boundary spanner between agencies and reduce the gap between information demand and supply for key information needs. However, the different respondents are not consistent on the existence and role of the information manager in the current situation. Most experts do agree though that an information manager will be increasingly important in the future. The respondents agree that currently, information is shared according to predefined authority structure, which is to hierarchical to address emerging information quality issues. In the collective information architecture, the collocated emergency control room has a crucial role in the information sharing and coordination process, but is limited in its capabilities to assure information quality. Currently, Rotterdam is one of the few regions in the Netherlands, which has a co-located control room, which means that the control rooms of the police, fire brigade and ambulance services physically located in the same office. Three respondents suggested the implementation of an information manager in the collocated emergency control rooms because much information passes through this multi-disciplinary unit. Five respondents mentioned that they are currently focusing on extending the capabilities of the plotter with enrichment capabilities (e.g., dynamic display of the number of first responders in the disaster area).

Findings from the field observations

During the observations, we experienced varying importance of the information manager and the situation plotter role. Generally, we observed that both roles are not very institutionalized in the decision-making units, which means that the other relief workers generally consider these roles as passive black boxes in the decision-making process. Moreover, we observed that commanders in the decision-making unit did not even know what the capabilities of the information manager were. For example, we observed some commanders who needed to contact their subordinates in the field, searched for telephone numbers by contacting the emergency room. This usually took more than a few minutes as every call to the emergency room was queued and not prioritized. Information managers were generally concerned with writing a situation report based on his interpretation of the situation as discussed during each decision-making round. Each decision-making round is led by a chair (leader of the unit) who pulls and prioritizes information from the commander of the various relief agencies (i.e., police, fire department, ambulance, port police, chemical experts). We extracted two rules for information pulling guiding the information sharing process: agency based (e.g., in case of a fire, the commander of the fire department is questioned first) versus event/priority based (e.g., who knows something about the victims in the area?). We see that less experienced information manager fully dedicate their attention to listening and typing, focusing on capturing information from the information sharing process, which is led by the chair of the decision-making unit. On the other hand, the more experienced[1] information managers are more active in the information sharing process and ask exploratory, explanatory and confirmatory questions while information is being shared. For instance, one information manager pointed out conflicting numbers on the death toll, requiring the commanders of the police and the fire department to recheck their sources. In this way, the information manager also acted as an information quality monitor. In the Rotterdam case, multiple information managers were frustrated by having to generate each situation report repeatedly and not be able to update changed information in earlier reports. This because reporting software they used did not provide capability to label information as new and updated for instance by bolding or highlighting information in previous situation

[1] we asked information managers to state their experience level prior to each exercise

reports. Moreover, the fact that the situation reporting software they used is a thin client internet application, which frequently failed if the wireless internet connection is lost, frustrated them because they had to retype a new document and did not know which information was most timely. A workaround used for this is typing the situation report in Microsoft Word and copy pasting the text in the online situation reporting software.

Our observation shows that information sharing is an unstructured process using multiple channels (voice, text and visual) and that the information sharing process is primarily supply driven and secondary event driven. Moreover, the roles and capabilities regarding information sharing and coordination are designed for hierarchical operations and are non-adaptive to situational needs. We also found that the information management process is not considered different from the decision-making process, so the roles and capabilities regarding these processes are not decoupled.

A fire department officer (Rotterdam) or a water board official (Gelderland) played the role of plotter during the exercises. The plotter is usually outside the decision-making unit and functions as low control (close to the incident). Plotters are expected to aggregate information into maps, pictures and figures of the situation and share this with the information managers in the decision-making units. The capabilities the plotter had available were similar for both cases and comprised of data visualization and map generating applications. In addition, the plotter had the capability enrich the plots by adding meta-information on the wind speed and potential hazard area. The latter capability proved very valuable for a number of the exercises in Gelderland, were the commanders of the relief agencies needed to develop a common operation picture on the area that would be flooded. In Gelderland the decision-making unit on the strategic level did have a beamer which could project such information on a whiteboard. In Rotterdam however, the decision making units on the tactical level did not have a beamer, so the chairman either sketched the situation on a large paper map or on the whiteboard based on his understanding of the plot he'd seem on the laptop screen of his information manager. This often resulted in messy drawings on the whiteboard as illustrated in figure 2.

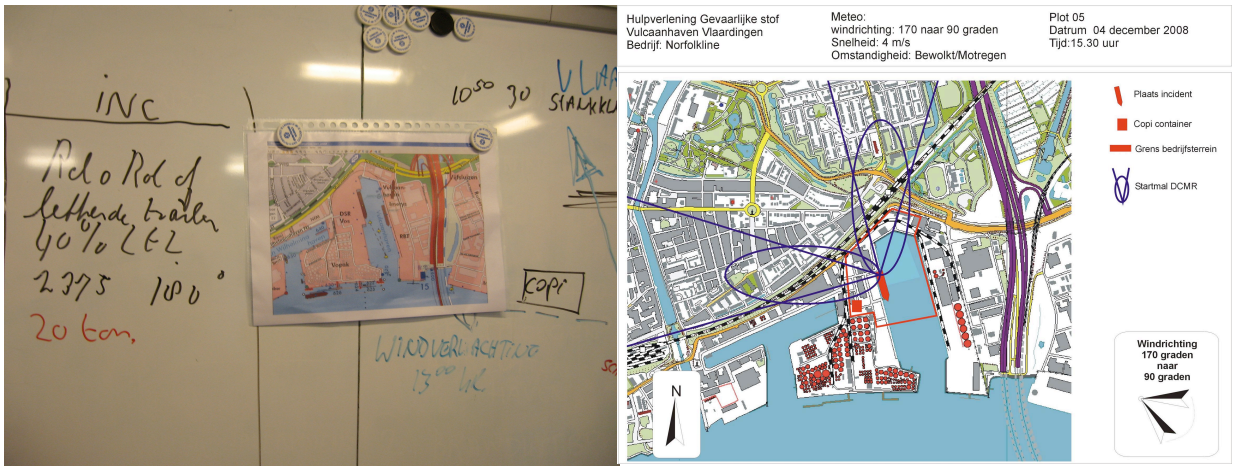

Figure 2: Plot on whiteboard (left) and computer plot (right)

Another lack of capabilities we observed was that of being able to access third party databases on the fly. For instance, during the flood exercise in Gelderland, a potentially dangerous chemical was spilled from of the ships affected by the dike break. In order to asses the potential hazards and determine the necessary counteractions, the relief workers wanted to know what chemicals were on the ship. This data was available in the database of the shipping company, but could not be accessed directly. Consequently, relief workers had to wait for two hours before this information was available via the emergency control room. In Rotterdam we observed a similar case, but this time the relief workers did not use the control room to find information but did this themselves by using Google to find information on hazardous materials. Even though this approach was much quicker, relief workers had some problem of filtering the information in Google using the correct search terms and could not guarantee the reliability of the information they found and used.

DISCUSSION AND CONCLUSIONS

During disasters, multiple agencies need to collectively decide and act to the threats of the disaster. Both decision-making and action depend on information, stressing the importance of information management as key processes in the disaster management cycle. In order to provide relief workers with high quality information under dynamic and unpredictable circumstances, information flows between demand and supply need to adapt to the changing conditions of a disaster. Achieving adaptivity is difficult because the boundaries between

information demand and supply are often blurred, indicating that the information demand (e.g., first responders) can at the same time be part of the information supply. We argue that the key for improving adaptivity lies in the development of roles and dynamic capabilities. Using two principles from coordination theory, we propose a set of dynamic capabilities for improving adaptivity.

Our field studies indicate that information management is not considered to be a full time process requiring multiple, dedicated roles and capabilities. Due to the low occurrence of disasters, relief workers do not have a good overview of who is responsible for certain information management roles and what sorts of capabilities are available in the decision-making unit. Our results suggests that response processes and information management processes need to be decoupled. Information reuse and access to third party sources are necessary capabilities. Moreover, we found that at the least the following five roles should be addressed 1) chair, 2) aggregator, 3) history and event manager, 4) information searcher and 5) expert panel. In addition, a number of dynamic capabilities are necessary which need to be developed across agency and echelon boundaries. Furthermore, we found that four groups of essential dynamic capabilities are necessary in disaster management: 1) preemptive, 2) protective, 3) exploitative and 4) corrective. Each of these groups contains a number of dynamic capabilities, which in a specific configuration build up a role and require one or more technical functionalities.

Our field studies were limited to exercises and we did not include the analyses of real disasters. In additions, we were only able to capture two types of disasters in our analysis. We especially recommend conducting further in-depth case studies on a larger variety of large-scale disasters in other countries to better understand and extend the proposed roles and dynamic capabilities. Further research is needed to extend and validate the proposed roles and capabilities and eventually to standardize these across multiple relief agencies on the local, regional and national level. Even though the roles and capabilities are generic and would ideally benefit all relief agencies, we expect that because of the cultural, institutional and operational differences between relief agencies, standardization and adoption will pose significant challenges for disaster management coordinators.

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