Managing Coordination in Emergency Response Systems with Information Technologies

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ABSTRACT

An emergency response system is a multi-disciplinary concept that includes not only information technology (IT), but also social communication networks of response agents, and organizational designs. The complexity of the system, the dynamic environment in which the system is embedded, and its technical constraints imply serious coordination problem. Based on coordination theory and theory of task-technology fit, we develop a model to guide our research to establish a better understanding of the impact of IT on coordination in emergency response systems. Particularly, in this research, we identify dependencies in the system, propose corresponding coordination mechanisms, and generate a set of propositions explicating the fit between technology attributes and coordination tasks.

Keywords

Emergency response system, coordination, dependency, task-technology fit.

INTRODUCTION

Emergency is any natural or man-caused situation that results in or may result in substantial harm to the population or damage to property. Emergency response is the process of gathering resources and acting upon the problems immediately after the incident happens. While the scope of emergencies can be very broad, the motivation of this research comes from the increasing attention on homeland security after the September 11 terrorist attacks in the United States. Thus, in addition to forces of nature, we identify seven threats as the basis for managing emergency response. They are: (1) human, (2) biological, (3) nuclear/radiological, (4) incendiary, (5) chemical, (6) explosive, and (7) cyber attacks against information and data systems (Illinois Homeland Security Summit, 2002).

With emergencies at the scale we defined, response actions and relationships can be very complicated. We adopt Calloway and Keen's (1996) idea and define the *emergency response system* as a multi-disciplinary concept that includes not only information technology (IT), but also social communication network of response agents, and the organizational designs. Thus, how to coordinate the activities in such a complex system for effective response is not easy to answer.

This research is aimed at providing a better understanding of the impact of IT on coordination in the context of emergency response. Our research question is three-fold:

1. What needs to be coordinated in an emergency response system?
2. What are the coordination mechanisms required?
3. How can information technologies help provide those coordination mechanisms?

We will start by describing the emergency response process and the system. Then, we will explain our research approach including research method and our conceptual model. Next, we will discuss the coordination needs followed by the mechanisms identified. Finally, we will present our current stage of the research and the anticipated further development.

DESCRIPTION OF EMERGENCY RESPONSE PROCESS AND SYSTEM

A General Description of Emergency Response

The emergency response process from the occurrence of a threat or an incident to the assembly of responses and actions is illustrated in figure 1.

In general, the response to a threat starts first at the local level. The local agent on-site identifies the situation and makes proper assessment on the severity of the event. If the event is believed to be containable within the local area, the local agent will simply act upon it with its own knowledge and expertise, and according to its established operation protocol. As the event intensifies, regional and federal agents may be notified. In this case, an emergency response coordinator is usually set up to act as the chief commander of the overall operation.

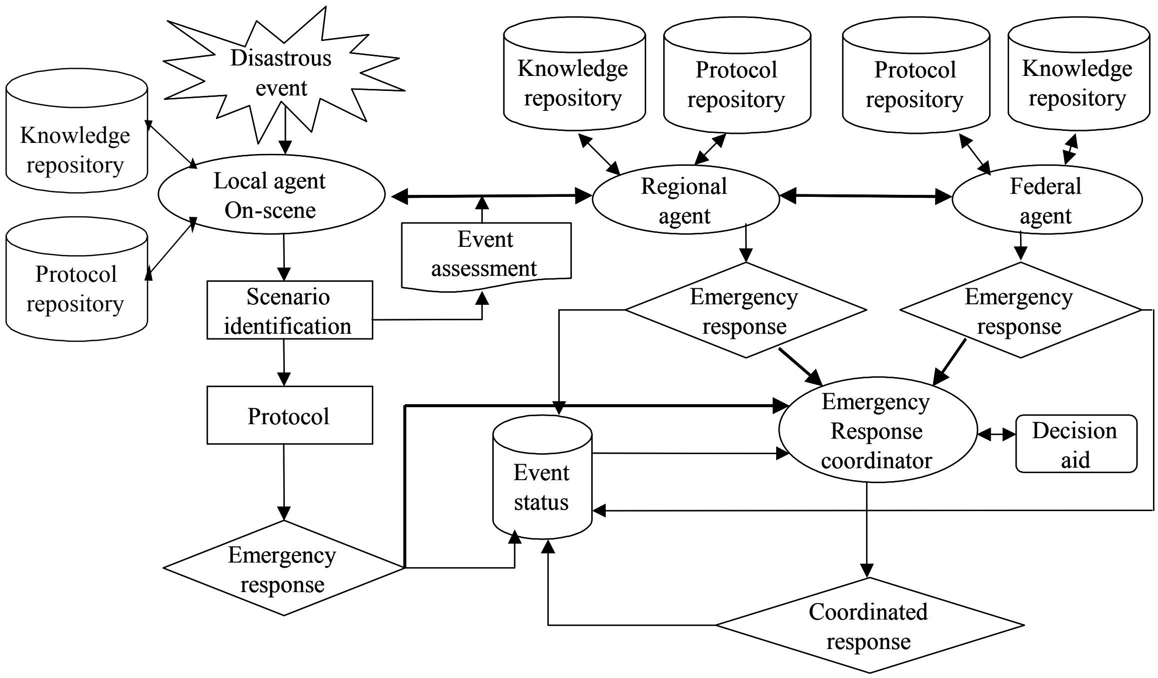

Figure 1. General Description of Process and Information Flow in Emergency Response

Relevant Response Agencies and Groups

We will study the emergency response agencies and group by analyzing one well-known emergency response system – Incident Command System (ICS). ICS is a standard response approach employed by the National Fire Academy and other public safety professionals nationwide. It is also the cornerstone of National Incident Management System (NIMS) and National Interagency Incident Management System (NIIMS).

The ICS organization is built using the top-down approach with responsibilities and performance initially placed with the Incident Commander. As need arises, four functional sections can be established. Each function has its own branches, with a set of primary and supporting agencies. Note that figure 2 below shows just a partial organization chart of ICS, focusing on the operations function only. Also, although many additional agencies can be involved in operations, only the primary agencies are listed as examples.

The organization of ICS demonstrates the following characteristics:

- Clear top-down command and control although the exact structure is adaptive to the situation. All the commanding positions (those in boxes in Figure 2) are arranged hierarchically and related to one another on the basis of formal authority.
- Multiple organizational goals. Basic system objectives and plans are established at or near the top of the hierarchy and used as a basis for decisions and behaviors at lower levels. However, each function area can have its own sub-goals from its functional focus. This decomposition continues along the organizational levels.

- Multiple protocols. At any level, responses are made based on protocols. However, with the extremely dynamic emergency situations and the complexity of agent structure, non-compatible protocols will probably always exist in operations.

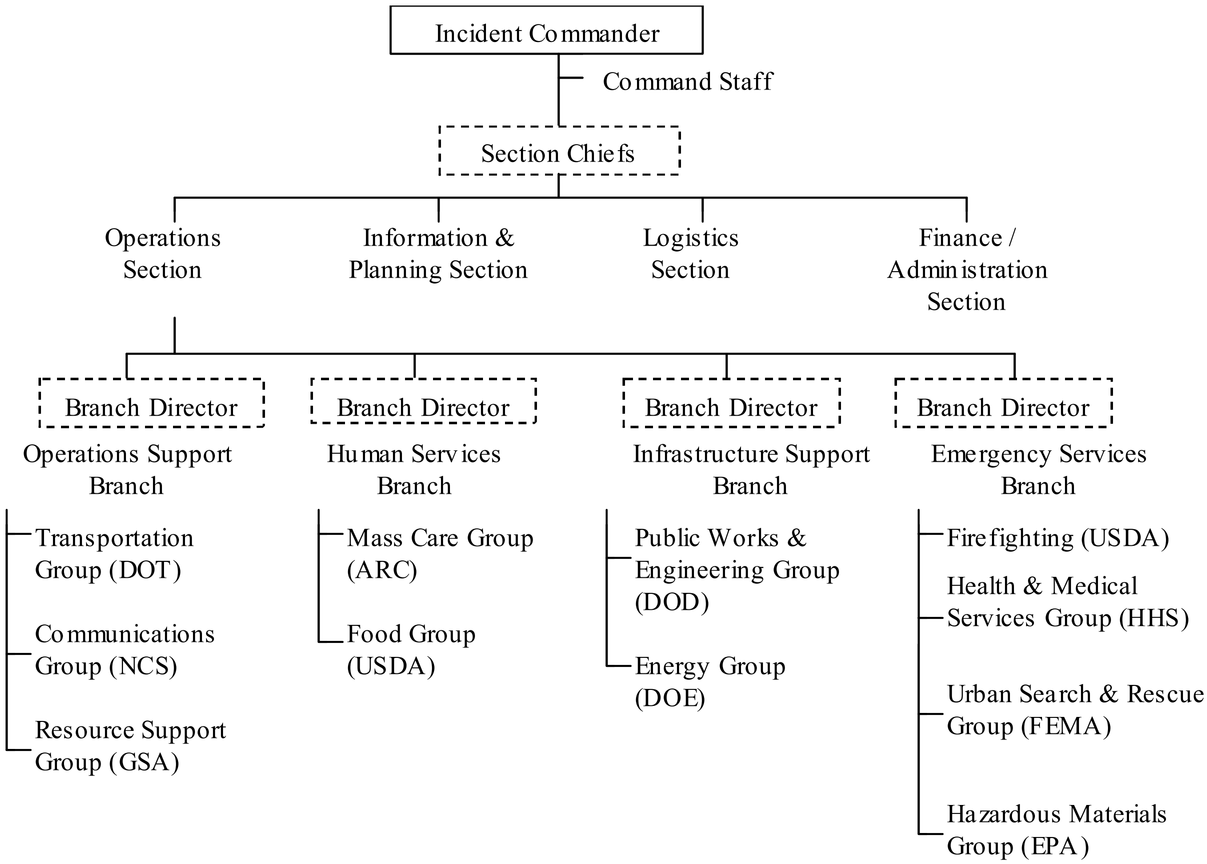

Figure 2. Partial ICS Organization

Interleaving Process Presentation of Emergency Response

While figure 1 shows a generic emergency response process at the very high level, a more detailed analysis of the process can be conducted by applying the interleaving perspective (Segev, Patankar and Zhao, 2003). We adopt this perspective because it emphasizes processes across organizational boundaries. Thus, we can illustrate the process with an example.

The scenario starts with a fire breakout at a vacant building in a small town. To simplify our case while at the same time show the complexity of emergency response, we consider eight major agencies (firefighters, policemen, mayor's office, Emergency Medical Services or EMS, Environmental Protection Agency or EPA, public health, Red Cross, and federal agencies such as FBI) participating in the following thirteen response tasks:

1. dispatch upon a 911 call
2. firefighting
3. traffic control
4. hazardous material investigation
5. take care of victims
6. prepare media statement
7. confirm resource access
8. analyze air sample
9. notify hospital
10. prepare shelter and food
11. request additional fire engines
12. request Federal aid
13. weapon investigation

The overall response process is divided into three stages proceeded in time: (1) first response, activated by local firefighters and policemen immediately after the 911 call; (2) local / regional response; and (3) emergency elevation, in which the severity and scope of the emergency is increased to beyond the capabilities of local or regional agencies, and federal resources are involved. We provide a visual illustration of this process interleaving in figure 3. The numbers in the diagram represent specific tasks indicated earlier. As figure 3 shows, these processes are not carried out sequentially, but interleaved. From the figure, it's obvious that even in a relatively simple emergency response environment, the agencies involved in this response effort must interconnect their own activities and processes very closely. Misconnections at any point could affect the overall progress of the response.

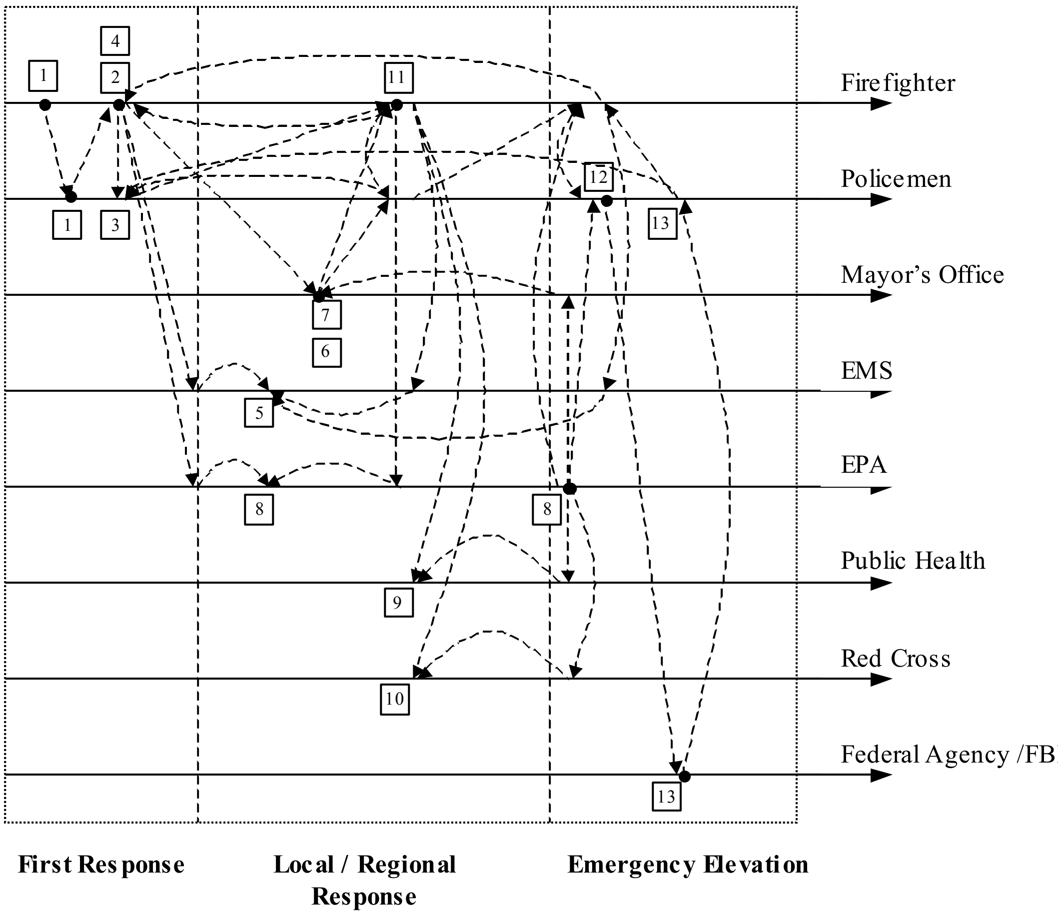

Figure 3. An Interleaved Process of Emergency Response

RESEARCH APPROACH

Conceptual Model

We base our research on two theories: coordination (Malone and Crowston, 1994) theory and the theory of task-technology fit (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998). We show our conceptual model in figure 4 below.

Coordination is managing dependencies among activities (Malone and Crowston, 1994). Using coordination theory and concepts from the organizational process handbook (Malone and Crowston, 1994; Malone, et al. 1999), we decomposed the coordination problem in emergency response into two parts: (1) the dependencies during response, and (2) the mechanisms to manage them. There are three generic types of dependencies: sharing, flow and fit (Malone et al. 1999). However, we are particularly interested in their specializations in the context of emergency response. Moreover, we explicitly added structure as another mechanism to coordinate activities (Jablin, 1987; Hengst and Sol, 2001).

The next step is to apply the theory of task-technology fit (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998) to link the identified coordination mechanisms with technology. Technology attributes will be analyzed along two generic dimensions (communication support and information processing) to determine their fitness to the requirements of the mechanisms.

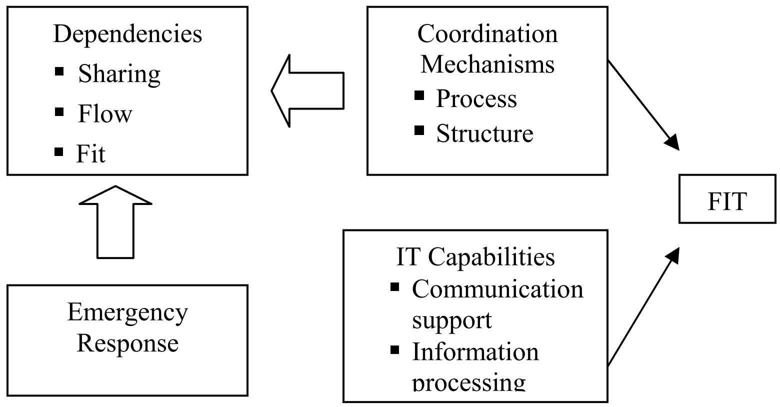

Figure 4. Model of IT-Enabled Coordination for Emergency Response

Research Method

We begin our research with theoretically guided investigations of dependency problems in emergency response and appropriate mechanisms for managing those dependencies. Then, driven from existing literatures, we will classify technology capabilities and define their underlying attributes. Following that, propositions will be developed on the use of IT in fulfilling coordination needs. These propositions will be substantiated by data collected from a variety of first-hand and second-hand sources: articles, reports, and case studies, as well as interviews, workshops, and tutorials offered by the Illinois Fire Service Institute.

DEPENDENCIES

Dependency can be classified in different ways. We choose to use the process perspective from Malone et al. (1999) as it embodies representations of the range of dependencies that exist in the emergency response situation. Follow their classification, we consider three types of dependencies: sharing, flow and fit. Sharing dependency occurs when multiple activities need to use the same resources. Flow dependency appears when the output of one activity is the input of another. Finally, fit dependency arises as the outputs of multiple activities need to fit into a single product (resource).

Generic Dependency	Specific Dependency		
	Activity-Actor	Activity-Activity	Actor-Actor
Sharing	Task assignment, some agents may be assigned to perform multiple activities, e.g. firefighters are assigned to put off the fire and rescue victims at the same time	Some activities must happen simultaneously, e.g. putting off the fire & traffic control	Response personnel share a common resource, e.g. the network bandwidth for communication
Flow	Delegation of agents to particular activities	Some activities are the prerequisite of others	Agencies get involved in a particular sequence, e.g. local, regional, to federal
Fit	Agents must be capable to perform the tasks	Some activities may interact or have counter effects	Agents must have compatible goals

Table 1. Dependencies in Emergency Response

Since coordination can be seen as the process of managing dependencies, and each process is composed of *activities* performed by *actors* through consuming certain amount of *resources*, thus dependencies are related to *activities* performed by *actors* through consuming certain amount of *resources*. Since resource consideration is already intrinsic in Malone's categorization, we include the combinations of activity and actor as additional dimensions. The dependencies identified are listed in table 1.

The first column represents the resource dependency as actors performing activities. An actor may have to use the same resource (e.g. his time) for several activities (sharing), have to be assigned to the job before taking any action (flow), or have to be capable of performing the specific activity (fit). The second column shows the resource dependency among activities. When activities must be carried out simultaneously, there is a sharing dependency. When one activity is the prerequisite of another, there is a flow dependency. When activities interact and trading off their effects, there is a fit dependency. The last column shows the resource dependency among actors. Agents may have to share a common resource (sharing), to follow a certain sequence to participate in response activity (flow), or may have different goals (fit).

COORDINATION MECHANISMS

We consider two types of coordination mechanisms: structure and process because they are in fact mutually sustained in an organizational setting: coordination structure provides the necessary links that fulfill the process, and coordination process in a way builds the structure by demanding the way decisions are made and communications are conducted.

Coordination Structure

Malone (1987) included decision-making and communication patterns as components of coordination structures. However, since the environment of emergency response can be extremely diverse and totally dynamic, it requires a modular-based structure to the extent that its components can be separated and grouped in a variety of ways while the system's overall functionality relative to environmental demand is maintained or enhanced (Schilling, 2000). Therefore, we consider coordination structures to contain three elements: modularization, communication pattern, and decision-making pattern (see table 2).

There are two aspects of modularization. First, it is denoted in network construction. An emergency network is built around the basic elements (modules) that apply in both routine and non-routine situations of all sizes. Rules, standard procedures, policies, and instructions within and across modules can also be formalized. Thus, the initial construction of all emergency response networks is in approximately the same way. In addition, it is involved in network reconstruction. If the existing network turns out to be not effective or is confronted with new difficulties, it can be disengaged or reconfigured.

In general, decision-making can be characterized by its centralization (Malone and Crowston, 1994). Centralized decision-making, or authority, facilitates coordination by eliminating or reducing the chance of conflict in resource allocation as actors performing various functional activities, thus keep the overall organization focused on its goals. However, it places a high demand on good, decision-relevant information to be provided continuously to the decision-maker as problem situations evolve. On the other hand, coordination by decentralized decision-making promotes flexibility and responsiveness by allowing lower-level actors to capitalize the knowledge and information from their direct contact with the problem situation to make on-the-spot decisions whenever problems arise. However, the draw back is that it puts more pressure on the monitoring and measuring of individual and team performances.

Coordination Structure Components	Explanation
Modularization	Response organization built around basic elements (modules). Can be constructed in approximately the same way and reconfigured easily (Schilling, 2000)
Decision-making pattern	Degree of centralization or decentralization of decision rights (Malone & Crowston, 1994)
Communication pattern	
Direction	The extent to which a communication link is formed from one actor to another (Monge and Contractor, 2003). We consider vertical (cross-hierarchical level) and horizontal (across-agency) directions.
Timing	Whether information will be delivered in real time as the event happens Whether the communication is synchronous or asynchronous

Table 2. Components of Coordination Structure

We are particularly interested in two elements of a communication pattern: the direction of communication, and the timing of communication. Timing is obviously extremely important because any emergency response is time critical. Direction measures the extent to which a communication link is formed from one actor to another (Monge and Contractor, 2003). In any hierarchical organization, there can be two directions in communications: vertical or horizontal. We incorporate it in the communication pattern because it can reflect the decision-making pattern and is essentially embedded in all kinds of emergency response processes.

Coordination Process

There is an abundance of coordination processes proposed in literature (see table 3). Thompson (1967) listed three typical coordination mechanisms: standardization, planning, and mutual adjustment. Standardization is the establishment of routines or rules to ensure consistent activities taken by actors in the interdependent relationship. Coordination by standardization requires the problem situations to be relatively stable, repetitive, and few enough to allow the matching between rules and situations. Plan as a coordination mechanism means to establish schedules of actions of interdependent actors. It involves less routinization, thus is suitable for more dynamic situations. Coordination by mutual adjustment involves the transmission of new information, or feedback, in the process of action. It is the least rigid of the three. The more variable and unpredictable the situation, the greater the reliance on coordination by mutual adjustment. Furthermore, they made an observation that these three mechanisms can be distinctly paralleled to the three interdependencies they identified. Standardization is more suitable for coordinating pooled interdependency, plan is more appropriate for sequential interdependency, and mutual adjustment is more suitable for coordinating reciprocal interdependency.

In proposing the coordination theory, Malone and Crowston (1994) suggested some examples of coordination processes for managing dependency. For instance, shared resource dependency can be managed by "first come/first serve", priority order, budgeting, or market-like bidding. Prerequisite constraints can be managed by notification, sequencing, or tracking. As they said, their list of examples is by no means exhaustive. However, they did discuss the theories and multi-disciplinary approaches, such as economics, organizational theory and computer science, that may be useful for us to tackle other coordination problems.

Built on coordination theory, Crowston and Kammerer (1998) studied a specific case of coordination in software requirement development at two large companies. Thus, in addition to the coordination processes suggested by Malone and Crowston (1994), they identified a set of mechanisms to manage dependencies in the context of software requirement development. For example, they particularly added "manual review of features" to deal with the dependencies between requirements problem.

Researchers have also studied different coordination mechanisms in other domains. Gittell (2002) studied three formal organizational coordination mechanisms – routines, boundary spanners, and team meetings. These mechanisms are chosen based on organization design theory, and are tested in care provider groups. We consider boundary spanners to be a concern of coordination structure and have included it in network evolution. "Routines facilitate coordinated action by prespecifying the tasks to be performed and the sequence in which to perform them." (p. 1409). In emergency response setting, routines have long existed in the form of protocols, or plans, such as the Federal Emergency Response Plan, the State Emergency Response Plan and all kinds of local response plans. Empirical evidences show that they work best in low-uncertainty settings. Team meetings allow participants to coordinate tasks directly with each other. Although it is not certain whether team meetings are increasingly effective under dynamic conditions, there has been some evidence showing that more team meetings will be used as uncertainty increases.

Author	Problem	Coordination Mechanism
Thompson (1967)	Relatively stable, repetitive, few enough to allow matching between rules and situations	Standardization
	More dynamic situations	Planning
	Most variable situations	Mutual adjustment
Malone et al. (1999)	Fit	Boeing's Total simulation
	Sharing	"first come/first serve", priority order, budgets, managerial decision, market-like bidding
	Flow (prerequisite)	Detailed advanced planning
Malone and Crowston (1994)	Simultaneity constraints	Scheduling, synchronization
	Prerequisite constraints	Notification, sequencing, tracking
Crowston and Kammerer (1998)	Dependencies between software requirements	Manual review of features
Gittell (2002)	Low uncertainty	Routines
	More dynamic conditions	Team meetings

Table 3. Example Coordination Processes

Coordination Mechanisms for Emergency Response

Our observation from studies on coordination structures and processes shows that since dependencies are very domain-specific, the mechanisms to manage them need to be considered in specific context as well. We have shown the dependencies in emergency response in table 1, below is a summary of the corresponding coordination mechanisms we identified based on previous studies as well as our own suggestions.

For sharing dependency, a cross organizational liaison (boundary spanner) can be very useful for allocating limited resources among response activities or agencies. Such decisions are usually made at the top level. There is a lot of vertical communications as orders and status reports are transmitted between the field agents and the commander. Communications must be real time and synchronous to support synchronized actions. While prioritizing is the choice coordination process for this dependency, some standard procedures may also be useful for some mechanic activities that must be carried out simultaneously.

Planning is the key process to manage flow dependency. Although some of those plans may be already established as protocols or schedules and can be followed through during the response, many other plans need to be constantly changed or re-planned as situations change. Having a modular response team structure in place can great expedient the delegation of response agents. Real time, synchronized communication continues to be dominant as response plans, notifications of activity, and commands of actions must be exchanged without any delay.

Mutual adjustment, such as through team meetings, is a typical coordination process for agencies to negotiate among each other to adjust their respective goals and avoid conflicting actions. The fundamental objectives of the overall response system can be standardized across all agency groups. Once processes that allow automatic agent identification and dynamic resource allocation are established, the system can locate the capable agents in no time and ensure that the response agents always have enough resources. Modularization helps identify specialists for particular activities faster. While response decisions are made centralized at the high level to ensure the congruence of activities, more horizontal communications among agents cross different organizations are essential for adjusting the potential conflict in their goals and actions.

INFORMATION TECHNOLOGY CAPABILITIES

Technology has been defined in many different ways, from as general as any tools used by individuals in carrying out their tasks (Goodhue and Thompson, 1995) to specific systems (e.g. decision support systems) or applications (e.g. email). To analyze technology capabilities in detail, we adopt an approach that many researchers have used in describing technologies. We classify technologies in terms of two dimensions: information processing and communication support (Huber, 1990; Zigurs and Buckland, 1998). Communication support relates to the fulfilling of communication needs of response agencies, such as media richness and choice, and time and space configuration. Information processing relates to the compiling, manipulating, and structuring of information. Each component can be further analyzed by detailed attributes.

Fit Between IT and Coordination Tasks

Theory of task/technology fit asserts that the appropriate use of IT for specific types of tasks should result in higher individual as well as group performance (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998). Viewing the resolution of various dependencies in emergency response (through the coordination mechanisms) as specific tasks, we conceptualize fit as a matching between effective performance of those tasks and attributes of information technologies. We hypothesize the fit under various task contingencies as follows.

Proposition 1: Managing sharing dependencies in emergency response requires real time information gathering and integration. Synchronous, low-bandwidth communication is preferred.

As we identified earlier, prioritizing is the mechanism that helps solve problems of shared public resources and multiple task assignments for one single agency. Coordination by prioritizing means that the response agency must make an assessment of the significance of actions that it can perform and the scarcity of resources, then make a decision on course of actions. Knowledge of current emergency situation is necessary in making such judgments. Therefore, data in various formats need to be constantly collected from a variety of sources and integrated to create such knowledge.

The communications between the boundary spanner (such as the functional group leaders) and individual agencies are essential in coordinating tasks jointly performed by multiple agencies simultaneously. Such communications need to be synchronous, that is, participants communicate at a designated time determined by the person requesting the conference (the group leader or the agency). The transmission of messages does not have to be multi-media but the timing is critical. Synchronized activities can be achieved by the real time correspondences of orders and quick status reports between the group leader and various agencies.

Dependency		Coordination Mechanism	
		Coordination Structure	Coordination Process
Sharing			
Activity-Actor	Task assignment	Real-time / synchronous communication	Prioritizing (Malone et al.)
Activity-Activity	Simultaneous activities	Use boundary spanners (Gittell) Centralized decision (Malone) Synchronous, vertical communication	Routine (Gittell,) Synchronization (Malone and Crowston)
Actor-Actor	Public resource sharing by agents	Use boundary spanners (Gittell)	Prioritizing (Malone and Crowston)
Flow			
Activity-Actor	Delegation of response agents	Use pre-establish modular team structure Real-time communication	Planning (Thompson)
Activity-Activity	Prerequisite	Centralized decision Direct command	Notification, tracking (Malone and Crowston) Planning / scheduling / routines (Thompson, Malone and Crowston, Gittell) Dynamic planning
Actor-Actor	Sequencing	Synchronous communication Centralized decision Direct command	Dynamic planning
Fit			
Activity-Actor	Agents capable of performing the response actions	Modularization (Schilling) Centralized decision	Automatic agent identification Dynamic resource allocation
Activity-Activity	Tradeoff of response effects	Centralized decision	Mutual adjustment (Thompson) Team meetings (Gittell)
Actor-Actor	Goal compatibility	Centralized decision More horizontal communication	Standardization (Thompson) Team meeting (Gittell)

Table 4. Coordination Mechanisms for Emergency Response

Proposition 2: Managing flow dependencies in emergency response calls for technologies that support information sharing and dynamic updating. Low-bandwidth communication is preferred.

Flow dependencies are reflected in interleaved response processes with frequent interactions among various agencies. The complexity of such processes exemplified in figure 3 indicates that it is very useful to plan out the steps of a response procedure before execution so that prerequisites will be fulfilled, and any resource constraint or conflict among agencies can be avoided. In practice, many of those plans, such as the Federal Response Plan (2003), are already established as "protocols." However, due to the extreme uncertainty in emergency situations, these procedures often need to be quickly re-planned. Effective coordination of flow dependencies requires the capability of dynamic planning – constantly monitoring the event and deliberately constructing new plans immediately after situations change. Having the ability to automatically update emergency information and share such information with other response agencies is critical to the success of dynamic planning, and ultimately, effective coordination.

Note that planning is usually done at the commander level because that's where the big picture of the situation is formed. Once a plan is made, commands for actions are communicated down to agencies in the field. Then, whenever a task is done, the responsible agency will notify the next agency in line as well as the commander. Thus, there will be a mix of frequent vertical and horizontal communications in the system throughout the response process. The messages in those communications are usually simple and straight forward, such as direct commands and notifications of task completion. Therefore, low bandwidth type of communication, such as text messaging, is more suitable to ensure such kind of rapid, frequent information transmission.

Proposition 3: Managing fit dependencies in emergency response entails database and knowledge management and computational capabilities of the system. Communications will take place using more diverse media choices and covering larger geographic areas.

Many emergency response tasks, such as hazardous materials handling, require very specific expertise from response agents. In this case, databases of agents can be set up at local response regions. When those databases are shared, authorized personnel will be able to locate the agent most capable for the task wherever that agent may be. Moreover, besides finding the right agent, it is equally important to make sure that the agent has the necessary tools, equipment, or other resources in order to perform the task. Dynamic resource allocation will not be possible without a resource inventory database that is constantly updated and linked to decision support applications. Computational capability can be utilized to simulate the effect of response actions. It is particularly useful to hypothesize the tradeoff of response actions performed by different agencies.

The communications taken place during team meetings or other forms of mutual adjustment are much more in-depth compared to those in managing sharing or flow dependencies. Simple text communication will not be sufficient for carrying out the negotiations among agencies. Rich media, such as virtual conferencing, need to be used to provide multi-media communication experiences for participants at various response locations.

SUMMARY, FUTURE DEVELOPMENT, AND CONTRIBUTION

In this research, we have accomplished the following key results:

- A systematic analysis of coordination needs (dependencies) in emergency response
- A literature-driven identification of various coordination mechanisms
- A set of propositions explicating the information technology attributes for effective support of those coordination mechanisms.

Future development of this research includes: (1) refine and substantiate the technology descriptions and propositions, (2) develop and test hypotheses on effective use of IT for emergency response coordination with real-world cases, and (3) generate ideal profiles of technologies for different coordination tasks. An ideal technology profile specifies all the matching attributes of IT and a particular task contingency. The greater the degree of adherence to an ideal profile, the more effective IT is used, or the fitter between technology and task. Thus, this profile can be used by as a benchmark to evaluate how technologies are used. It can also be used to suggest new technology innovations to improve coordination efforts and achieve more effective emergency response.

Theoretically, this proposed research offers an advancement of the theory of task/technology fit. Unlike in the theory, which either takes various technology applications as given packages (Goodhue and Thompson, 1995), or categorizing technologies at the most abstract level (Zigurs and Buckland, 1998), our detailed analysis of technology allows prescribe more specific solutions to coordination problems.

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