IMPROVEMENT OF COLLABORATION AMONG FIRST RESPONDERS INCLUDING CIVIL ENGINEERS DURING DISASTER RESPONSE IN URBAN AREAS

JeongWook Son[1] and Feniosky Peña-Mora[2]

ABSTRACT

As cities have expanded, they have become more vulnerable to disasters due to their reliance on highly engineered environments and the interdependency among infrastructure systems such as energy and transportation. In addition, it is expected that we will encounter disasters more frequently and that they will be more severe. Nevertheless, the triad of first responders including firefighters, police, and emergency medical service may bring about an inappropriate response picture; i.e., independently assembled command centers and resources; great difficulties in processing information, communication, and coordination; and inadequate roles for civil engineers.

Part of the problem has been identified as associated with their need to have high 'Situation Awareness'. In order to effectively meet work demand in distributed, dynamic, and chaotic conditions, first responders need high situation awareness; however, this need is unfulfilled in most cases due to their inability to access information, limitations of IT technology, and organizational problems [McKinsey&Company, 2002].

In this study, we explore a response framework into which civil engineers and IT components are integrated to help grasp the relation between situation awareness, collaboration, and performance. Then, the framework is embodied in a casual loop diagram to represent the disaster dynamics. As a result, it is expected that the situation awareness will have a positive relation with communication and coordination between response organizations and their performance. It is also expected that technical support of civil engineers and employment of new IT components would make a critical contribution to increasing situation awareness. These results will support the vision that in future disaster response scenarios involving urban areas, civil engineers could and should play a role as a fourth key disaster responder. In addition, it is expected that the support of civil engineers and IT components can increase the performance of responders by facilitating collaboration between responders through improvement of situation awareness.

1 Graduate Student, Civil and Envir. Engrg. Department, 3119 NCEL, Univ. of Illinois at Urbana-Champaign, Urbana, IL 61801, Phone +1 217/244-0691, FAX +1 217/265-8039, json3@uiuc.edu

2 Associate Professor, Civil and Envir. Engrg. Department, 3129b NCEL, Univ. of Illinois at Urbana-Champaign, Urbana, IL 61801, Phone +1 217/244-0187, FAX +1 217/265-8039, feniosky@uiuc.edu

KEY WORDS

disaster response, situation awareness, collaboration, organizational performance, system dynamics

INTRODUCTION

Today, concern about disasters in urban areas has increased due to increases in population density, population shifts, and highly interdependent infrastructure systems. Furthermore, it is expected that the exponential increase of disaster losses will continue [Mileti, 1999]. The fact that the $200 billion in economic loss caused by hurricane Katrina in 2005 and $33 billion in economic loss caused by the World Trade Center terrorist attack in 2001 while $27 billion in economic loss caused by other disasters around the world in 2002 indicate how severe the damage by disasters in urban areas can be in urban areas.

Nevertheless, the triad of first responders, firefighters, police, and emergency medical service may bring about inappropriate response pictures [McKinsey&Company, 2002; NCSEA, 2001]. It is believed that this is mainly because first responders at individual, team, and organizational levels are unable to develop a depth of understanding of the situation that would allow them to make comprehensive decisions and respond in a holistically appropriate manner. Several possible impediments to the development of this depth of understanding include unpredictable and dynamic work demands, diverse responders in the distribution area, inadequate support of response system to get the needed information, and so on.

Research into Situation Awareness (SA) by Ensley (1988) is applicable to help explain these phenomena in disasters. Since the definition and theoretical framework of SA [Endsley, 1988] originates from the field of aviation, it is difficult to directly apply previous work to this study. However, the theoretical background and framework of SA is expected to be of use to describe what the current disaster response is and to contrive how to improve it because of the similarity between its application area and disaster's conditions, and its ability to explain the whole process of person's reaction against complex and dynamic situations.

In order to enhance the SA in disaster relief efforts in urban areas, the role of original architects and civil engineers is expected to be invaluable. Prieto (2002) proposed their potential contribution as 4th responder in increasingly engineered environments exemplifying the case of September 11 terrorist attack (2001). In addition to contributions from architects and civil engineers, IT components for better communications, data acquisition, data transmittal, and data processing are also thought as potential contributors to increase SA and to help civil engineers support.

RESEARCH BACKGROUND

SITUATION AWARENESS

"Situation Awareness (SA) is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [Endsley, 2000]. Situation awareness is a cognitive construct that refers to an awareness and understanding of external events in our immediate and near future surroundings. Researchers and practitioners have considered SA as critical for accurate decision-making and performance in a variety of work domains such as air traffic control, general aviation, nuclear power plant management, medicine, and driving.

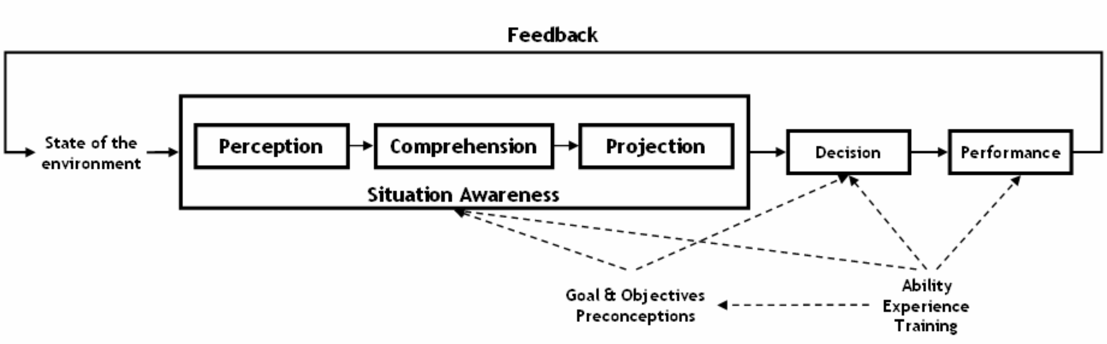


Figure 1: Model of Situation Awareness in Dynamic Decision Making [Endsley, 2000]

Researchers in SA field maintain that there is a huge gap between the tremendous amount of data available and people's ability to discern what is necessary to make effective decisions. This information must be usable cognitively and physically in order to be integrated and interpreted in a correct manner [Endsley, 2000]. The researchers' main objective is to know how well the system supports the operators' capability to get the necessary information under dynamic environments.

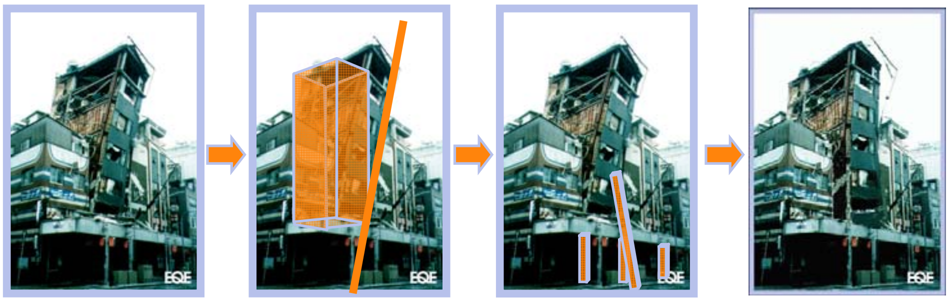
SITUATION AWARENESS IN DISASTER RESPONSE

Since the basic concepts and underlying framework of SA were primarily made for study of aviation operation, it is essential to refine the definition of SA to apply disaster response processes. In this research, SA is understood as "the state of being conscious, sensible, alert, and vigilant for situation" (in the definition, situation is defined as the combination of significant information extracted from the environment at a give time), which is reached through perception, interpretation, and prediction processes.

In the definition of SA, 'conscious' emphasizes the recognition of something sensed or felt, 'sensible' implies knowledge gained through intellectual perception, 'alert' stresses quickness to recognize and respond, and 'vigilant' implies being ever wary of potential dangers. The state of SA is divided into four classifications because first responders who have their SA are thought to respond in four different conditions of response in accordance with their level of situation awareness.

In particular, responders who are in the following states of situation awareness are able to 1)perceive the situation; however, they may not be able to understand what they perceive due to lack of knowledge, experience, training, and so on (conscious), 2)understand what they perceive but cannot determine an appropriate response (sensible), 3)understand the situation and can respond appropriately, but they are not capable of predicting what is going to happen in the future (alert), and 4)predict what will happen in the future as well as understand and respond appropriately to the situation (vigilant).

For example, let us suppose that several firefighters are responding to a collapsing building. If a firefighter is in the state of conscious, he has the perception of the environment much like photo (a) in figure 2 - in some cases, he may not even be conscious. If he is in the state of sensible, he is able to acquire knowledge regarding the situation through intellectual processes; he understands the leaning of the building compared to its original shape in picture (b) - but he cannot appropriately respond to it. In the state of alert, he reinforces the building to prevent collapse of whole building as seen in picture (c) because he has adequate understanding and knowledge to do it. In the vigilant state of situation awareness, he is able to predict whether the building will wholly collapse or not in future.



(a) Conscious (b) Sensible (c) Alert (d) Vigilant

Figure 2: Different States of Situation Awareness

SA has been used to ensure that system is provided in an effective way that is usable cognitively as well as physically and to know how well system supports the operator's ability to get the needed information under dynamic operational constraints. Similarly, SA is expected to be useful in explaining the state of disaster response by evaluating the SA of a previous response, contriving new ideas to enhance response performance, and examining newly developed systems for disaster response. Recently, many reports have addressed recommendations to overcome problems that have occurred during previous disaster relief efforts, and research papers have proposed newly developed systems for better disaster response. These findings and contrivances should be helpful for future responses. However, it is vary delicate work to explain their expected effects in a comprehensive and systematic fashion, because disasters in urban areas are extraordinarily complex events attending massive response efforts.

In this context, considering that SA is acquired from the environment through direct observation; information system; and communication with other members, and such acquired SA would affect disaster relief, SA is thought to be able to play a important role in explaining complicated response processes connecting different parts of disaster relief efforts.

ORGANIZATIONAL SITUATION AWARENESS

So far, SA has been considered only at the individual level. However, complete urban disaster relief efforts can not be achieved by any single responder or organization, and the interdependency and complexity of disasters require extensive collaboration among different type and various levels of organizations, the concept of SA has to be considered at the organizational level. However, in this paper, the SA is assumed to indicate the sum of individual SA in a team or organization because the main purpose of this paper is to present the disaster response framework and more study on organizational SA is need to identify the relation between individual SA and organizational SA in disaster response.

SITUATION AWARENESS IN CURRENT DISASTER RESPONSE

Because disaster conditions require collective responses of whole organizations, communication and coordination is significant to form SA. However, according to several reports, former disaster responses have demonstrated numerous shortcomings in the ability to access information, the lack of standardization and coordination, and poor communication in general[National Research Council, 1999].

In the following section, factors affecting forming and maintaining SA are addressed based on a literature review and case study as a preliminary stage to a develop disaster response framework that includes situation awareness.

UNPREDICTABLE AND DYNAMIC WORK DEMAND

Conditions during disasters are highly unpredictable and the work demands generated by the disaster are dynamic. Therefore, there inevitably exists delay in information acquisition and response, as well as a difference between actual and perceived data. For instance, during the response to hurricane Katrina (2005), newspapers reported that the there was difficulty in estimating the exact death toll and economic damages because of consecutive breaches of levees and the resulting flooding. Figure 3 shows an estimated death toll during hurricane Katrina. Because we do not have exact actual number of deaths as they occurred, we cannot compare between actual and perceived lives lost. However, judging from several reports, it is certain that there was delay in getting information after events happened, so that the first responders had to work with perceived data that differed significantly from actual data.

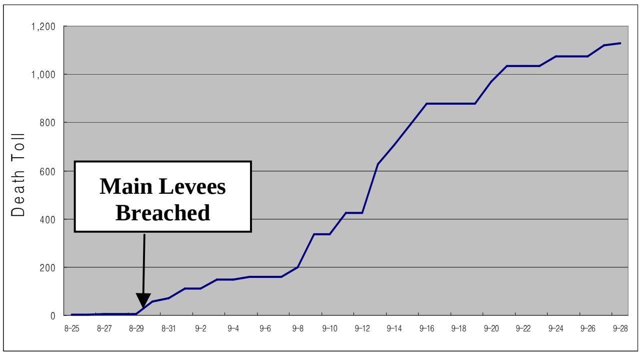


Figure 3: Death Toll Estimation during Hurricane Katrina (CNN,08/26/2005~09/28/2005)

Furthermore, rapid improvements in technology have enabled greater degrees of interdependency [Mendoca et al., 2004]. Consequently, concern with cascading effects among infrastructure systems is increasing. Communication failures across conventional phone lines, cell phone systems, and overloaded radio channels following the 2001 World Trade Center attacks critically damaged the capacity of emergency response organizations in action and illustrated the vulnerability of interconnected metropolitan regions exposed to high risk.

DISTRIBUTED & MULTI ORGANIZATIONS

Because disaster unfolds dynamically, it requires dynamic and distributed decision making; in addition, some tasks require collaboration between several organizations to develop a solution due to the composite aspects of disaster and an individual's limited ability. In other words, a broad scope of information and tasks concurrently occurs at various places; however, each responder can not alone process all the information and respond to tasks by himself because each responder and each organization has limited ability and information; therefore, it is necessary for first responders to collaborate with other responders and organizations.

Yet, according to several reports, they are thought to have failed in most previous disasters; i.e., responders inside of the World Trade Center during response to Sept. 11 terrorist attacks did not have complete and reliable information on what was happening outside of the buildings such as the overall picture of incident area, the condition of the buildings, and the progression of the fires. They could not even access reports from television and an NYPD helicopter.

INSUFFICIENT TECHNICAL SUPPORT

Comfort (2004) pointed out the significance of 'core information' in disaster response. Organizational effectiveness in disaster response depends substantially on communication, particularly collection and distribution of accurate information [Petrescu-Prahova and Butts, 2005]. Core information in disasters in urban areas is thought to be most related to buildings and infrastructure systems as well as search and rescue operation, which are the main objects of damage because of their high density and interdependency in urban areas. However, many reports claimed that first responders were unable to get such core information and this failure has led them to undesired consequences. For example, during the response to the Sept. 11 terrorist attacks, the incident commander could not get any information concerning the structural integrity of the World Trade Center sufficient to estimate the situation [McKinsey&Company, 2002]; this failure contributed to the catastrophic damage.

LIMITATIONS OF IT COMPONENTS

Collecting, transmitting, and processing data, communicating to each other, and managing response resources are very essential processes during disaster responses. Performing these processes effectively is a critical factor for successful disaster management. In spite of this necessity, first responders have gone through difficulty with their systems for communication, collecting information, sharing information, resource tracking [McKinsey&Company, 2002].

ALTERNATIVES TO ENHANCE SITUATION AWARENESS IN DISASTER REPONSE

TECHNICAL SUPPORT OF ORIGINAL DESIGNERS AND CIVIL ENGINEERS

So far, the role of civil engineers as key responders in disaster response has been overlooked. They have performed limited roles as a small part of the command of operations section in the Incident Command System. However, considering that civil engineers have designed, constructed, and maintained building and infrastructures in urban areas, it is clear that their knowledge, experience, and information could help existing first responders. For example, during the Sept. 11 terrorist attacks, the engineering and construction industry voluntarily reached out to provide technical and construction expertise. Although protocols were not firmly in place and this "fourth responder" had not participated in response training, the help of engineers and constructors has been critical [Prieto, 2002].

From the viewpoint of situation awareness, the role of civil engineers is more obvious. Because the main objects of damage in disasters in urban areas are buildings and infrastructure, civil engineers can provide first responders with appropriate information such as as-built drawing and maintenance data and they can analyze structural or environmental data collected from the site. That is, they are able to present critical information for first responders to form and maintain appropriate SA as the situation dynamically changes.

EMPLOYMENT OF IT COMPONENTS

As mentioned earlier, in most cases, first responders experienced difficulty in collecting data, sharing information, and communicating. Because the process to form and maintain the appropriate extent of SA in the dynamic and complex conditions of disasters presupposes exchange of collected information through communication, another important enhancement to SA is employment of IT components to collect, share, and analyze data, and communicate such as sensor systems, laser scanner, black in buildings, mobile ad-hoc network, and structural and environmental analysis applications.

In addition, such IT components in disaster responses also are expected to facilitate the role of civil engineers. Using these components, civil engineers in local or remote areas will be able to participate in each response process whenever they are needed, and they can determine the stability and environments of structures remotely.

Figure 4: Examples of IT Components for Disaster Response

DISASTER RESPONSE FRAMEWORK

Based on efforts described in the literature to develop a system dynamics model to examine the effect of SA in disaster response, a casual loop diagram to map feedback loop structure composed by occurring work demand and response process is drawn. In this feedback loop, the relation of SA with other processes is addressed from a holistic viewpoint, and the role of SA in disaster response is identified.

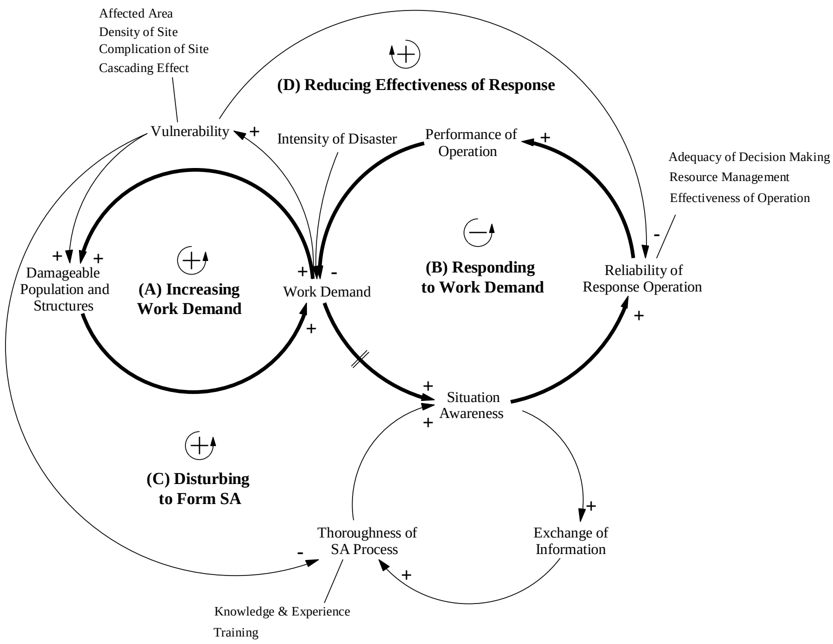


Figure 5: Casual Feedback Loop Framework for Disaster Response

In figure 5, when a disaster occurs in a certain area, initial work demand, meaning tasks and information demanding a response by first responders, would be dictated by the intensity of the disaster. The initial work demand gradually spreads according to the vulnerability of the area affected, which means how easily disaster site could be damaged by occurring work demand. The vulnerability of specific area is affected by affected area, density of disaster site, complication of the site, and cascading effect spreading between critical infrastructures. If population and structures which might be damaged by spread get relief by responders, the spread is relieved. However, if the spread is not relieved, the work demand continuously increases to a certain extent (reinforcing loop A).

To respond to the work demand, responders must form SA as they perceive the work demand. The level of SA depends on the thoroughness of the process. The thoroughness is affected not only by their individual abilities such as knowledge, experience, and training but also by information obtained through direct observation of environment, information systems, and communications with colleagues. Based on the obtained SA, they make decisions, manage response resources, and respond to disasters. Response operation reduces the work demand as the responders achieve their operation (balancing loop B). However, their efforts to mitigate work demand are often hindered by the distributed and complex environments of disasters in urban areas. First responders who located in wide area are disturbed in forming and maintaining high SA (reinforcing loop C). Their reliability is also deteriorated by such hostile environments (reinforcing loop D).

In figure 6, the response scenario with the inclusion of the technical support of civil engineers and employment of IT components is supposed. The civil engineers make a contribution to the process to form and maintain SA and provide help to make strategic decisions by using several applications to analyze and to integrate collected data. Also, IT components would be able t help first responders perceive the work demand and communicate. Additionally, IT components should increase civil engineers' contributions. Eventually, civil engineers and IT components would bring about facilitating communication and coordination among first responders by enhancing SA (reinforcing loop E).

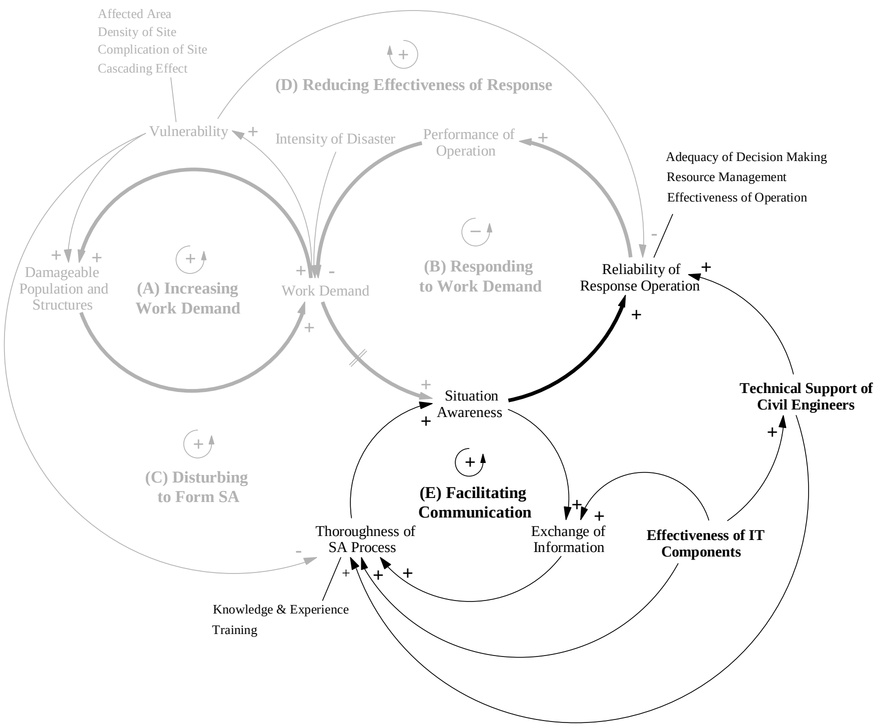


Figure 6: Enhancing Situation Awareness Feedback Loop

CONCLUSION

Disaster response in urban areas has demonstrated weaknesses such as the inability to access information, the lack of coordination, and poor communications; consequently, first responders experience numerous difficulties in dealing with a dynamic work demand. It is believed that this is because first responders lack the resources to grasp what was going on around them due to dynamism and complexity of the disasters.

For this, the concept of situation awareness is proposed to identify the mechanism to affect disaster relief efforts and to explore ways to enhance the performance of disaster relief efforts by increasing the situation awareness. Even though situation awareness in disaster contexts is not well defined and has not been formulated in a sufficiently detailed way to evaluate it, it is expected that consideration of situational awareness will provide a different point of view to think about disaster relief efforts due to its advantage of being able to account for human cognition processes and performance in dynamic and complex environments in many areas.

Since this research for developing system dynamics model of disaster response framework is ongoing; therefore, tentative conclusions are presented by using casual loop diagram in this paper. First, the SA in disaster response would be very useful to ensure that the response system is provided in an effective way and to know how well it supports the responders' ability to get the needed information under dynamic and complex conditions; second, it is expected that the more SA responders obtain, the more possibility they have to make correct decision and to respond in appropriate manner; finally, it is expected that both civil engineers' contribution and employment of IT component support for first responders to form and maintain high SA by facilitating communication and coordination.

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