UNDERSTANDING WORK WITH GEOSPATIAL INFORMATION IN EMERGENCY MANAGEMENT: A COGNITIVE SYSTEMS ENGINEERING APPROACH IN GISCIENCE

A Thesis in Geography
by
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ABSTRACT

This dissertation seeks to improve the utility of GIS by developing a deep understanding of GIS and geospatial information technologies to provide more suitable interfaces for emergency management centers. To design such interfaces and improve experts' access to GIS, it is important to understand how geospatial information is used in emergency management and crisis decision making. The immediate motivation for this research is to support a larger research effort to make GIS easier to use in emergency management and command and control situations. During emergencies, the standard operational delivery of geospatial information is channeled through GIS specialists, working individually, who provide emergency response managers maps and analyses for damage assessment assistance requests. Efforts have been made to improve the timely delivery of information during emergencies through widespread efforts to deploy geospatial information technologies in emergency management divisions across the country in support of emergency planning, decision-making, management, and response. Still, our understanding of the breadth and depth of geospatial information technologies in emergency and crisis response centers is limited. Recent advances in vision tracking, speech recognition, and interface design have opened the door on the design of multimodal interfaces to GIS. To develop a deep understanding of work with geospatial information, I implemented a three stage, problem-centered study based on theoretical foundations in Cognitive Systems Engineering, Naturalistic Decision Making, and Knowledge Elicitation. The knowledge obtained about current practices was used to create models and envisioned designs of advanced, next-generation geospatial information technologies. In order to provide design assistance, this work focuses on gaining an in-depth understanding of the use of geospatial information during emergency response activities, with specific focus on hurricanes. Improved understanding was achieved by the production of models of crisis decision-making and scenarios of the use of geospatial information during emergencies. A key component of communicating the information was through the creation of real world emergency response scenarios that serve as envisioned designs for more natural interfaces to GIS, new geospatial information technologies, and as representations of work in Emergency Operations Centers. This research suggests that the methods and theories of Cognitive Systems Engineering have the potential to improve both an understanding of work with geospatial information and the subsequent design of advanced, geospatial information technologies.
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DEDICATION

To my family & friends
who pulled me through.

And also to
Dean Coulter – you left too early buddy.
“There’s Plenty Good Room, Plenty good room...”
Chapter I
Introduction

“The beginning is the most important part of the work.”

--Plato--
1.1 Introduction

In 1900, a powerful hurricane caught residents of Galveston, Texas by surprise. The lack of warning systems, communications systems, and weather forecasting models left the community helpless as the storm approached. In that storm, more than 8,000 individuals died amounting to the largest loss of life from a hurricane event in US history. Ninety two years later, technological advancements shaped a much different situation when the United States was hit by the most expensive disaster in US history. On August 24th, 1992, Hurricane Andrew crashed into the eastern shore of southern Florida. The storm brought sustained wind speeds of 140 mph, with gusts exceeding 175 mph. Advanced warning of Hurricane Andrew kept the loss of life to 43, but the damage left over 175,000 individuals homeless. Incomplete intelligence reports obtained within the first 24 hours did not allow the first responders to understand the nature of the hazard in relation to what was on the ground. Thus, supplies were not sent to the needed locations and distributed efficiently during the critical period immediately after the catastrophic event. Many citizens did not receive immediate food and shelter assistance until over three days after the storm had made landfall. This lack of immediate response and action prompted Kate Hale, the director of Miami-Dade County’s Emergency Management Office to ask the infamous question “Where in the Hell is the cavalry?” on live television, prompting lawmakers and responders into action (Barnes, 1998a; 280). As with all emergencies, the lessons learned during a specific crisis inform and better prepare the responders for the next disaster. During Andrew, poor communications and a lack of real-time damage assessment information prevented the timely delivery of needed resources. Had the emergency responders had access to a GIS with linked damage reports updated from the field, the cavalry would have likely arrived much earlier, preventing the embarrassment suffered by FEMA (the Federal Emergency Management Agency) and the lack of adequate support for the storm’s thousands of victims.

The overarching goal of this research is to capture and model explicit, tacit, procedural and inferential knowledge of crisis management and response and to mold that knowledge into models and designs that can be used to guide the development of new collaborative, geospatial information technologies for emergency management. This dissertation seeks to improve the utility of GIS (Geographic Information Systems) by developing an understanding of GIS and geospatial information technologies in the context of emergency management centers. To design interfaces that improve experts’ access to geospatial information, it is important to understand how that information is used in emergency management and crisis decision making. The immediate motivation for this research is to support a larger research effort to make GIS easier to use in emergency management and command and control situations. The remainder of the section
outlines the broader context for the research and details the specific research contributions; these include the potential to inform work on improving interfaces to geospatial information, understanding of GIScience applications, developing common ontologies of crises, establishing common ways of visualizing ontologies, dealing with uncertainty, support for architectural interoperability of geospatial information, and the representation of knowledge that promotes sharing and forms a basis of preserving institutional memory.

FEMA outlines multiple stages of emergency response activities: planning, preparedness, response, recovery, and mitigation (http://www.fema.gov/). Mitigation is concerned with the characterization of a given location’s vulnerability to various types of hazards. Once identified, steps can be taken to lessen the effects of hazardous events through both mitigative and preparedness activities. Preparedness involves careful assessments of local and state resources, and the ability of agencies and management teams to respond to a given emergency situation. Response, the most time critical step, consists of damage assessment as well as five secondary steps: warning and notification, immediate public safety, property security, public welfare, and restoration of services. The final stage of emergency management is recovery. In recovery, agencies work to provide the necessary assistance and aid for the communities in danger, and also work to outline mitigation and prevention strategies in the event of a similar disaster.

The access GIS provide to critical geospatial information makes the use of GIS appropriate for assisting in all phases of disaster and crisis management (including mitigation, preparedness, response, recovery). Emergency management in crisis situations requires multi-agency communication and collaboration about the spatiotemporal extent of hazards and disasters. In recent emergency situations resulting from both natural hazards and human-made disasters, GIS have been used to assist with the immediate response effort (Dash, 1997). In the immediate response to the 9/11 attacks, GIS were used to create new base maps of lower Manhattan for use by search and rescue teams, to identify utility outages, and for transportation planning (Thomas et al. 2002). Thomas et al. (2002) found that GIS maps were used not only for mapping the extent of the damage, but were also used to guide and direct the distribution and provision of relief supplies to rescue workers and affected citizens in damaged regions.

The standard operational delivery of geospatial information is channeled through GIS specialists, working individually, who provide emergency response managers maps and analyses for damage assessment assistance requests. An impediment to more widespread use of GIS in national, state, and county level emergency management centers is that today’s GIS are built for individual users interacting with the software on a personal computer, whereas most emergency response planning is done by groups of individuals (who are not always collocated), interacting
with datasets that include satellite imagery, real-time weather forecasts, and multiple GIS coverages printed as paper maps or displayed on personal computers. Moreover, GIS developers continue to increase the number of specialized software application extensions, tools, methods of data storage, and analysis features, further increasing the complexity of GIS and ensuring that only highly trained specialists are able to make use of such tools during emergency situations. Clearly, there is a need to not only simplify GIS interaction, but also to tailor it for multiple users addressing complex problems collaboratively, especially in time-critical applications such as crisis management. While the development of more natural interfaces, such as voice operated, unimodal natural language interfaces in GIS represents a movement towards a portion of the solution (Frank and Mark, 1991), much research on collaborative multimodal GIS interfaces is required before the true potential of GIS to assist emergency management is realized.

Efforts have been made to improve the timely delivery of information during emergencies through widespread efforts to deploy geospatial information technologies in emergency management divisions across the country in support of emergency planning, decision making, management, and response. Still, our understanding of the breadth and depth of geospatial information technologies in emergency and crisis response centers is limited.

A specific impediment to effective GIS use by decision makers in crisis situations motivates the research reported here – the difficult learning curve of current GIS that generally requires crisis managers to rely on a GIS specialist to act as an interface to data access. One way to make GIS easier to use is to improve the interface. Recent advances in computer science and information technology have opened the door on the design of natural, multimodal interfaces to GIS. Such interfaces have the potential to improve emergency managers and decision maker’s access to geospatial information during emergencies. Specifically, they can shorten the learning curve for effective use of GIS by supporting decision maker’s information requests as they occur now (i.e., support the communication that takes place between the decision maker and the GIS analyst) and by supporting interaction with map-based displays and simplifying complex software commands and operations.

A multimodal interface is one that provides the user with, literally, multiple modes of initiating commands and operations in computer software systems. Such modes can include, but are not limited to gesture, speech, gaze, head movements, facial expressions, hand shapes, sounds, and sketch based pen devices. Research in these transparent and multimodal interfaces (Cohen et al., 1999; Oviatt and Cohen, 2000, McGee et al., 2000; Sharma et al., 1998; Egenhofer, 1997; Sharma et al., 2001) suggests that these more natural interfaces are more efficient and preferred over the traditional WIMP (Windows Icons Menus Pointers) model of HCI (Human
Computer Interaction). Multimodal interfaces are still in the development stage, so they do not work on a regular basis with any commercial applications. The display and manipulation of maps in GIS is a well suited application domain within which to perfect the technology, since the maps provide a concrete context for perfecting interaction. The design of a gesture speech interfaced to a GIS is one problem context within which this research is applicable.

This work was initiated, in part, to assist with the design of a Dialogue-Assisted Visual Environment for Geoinformation: (DAVE_G), a collaborative, GIS-based emergency management system that responds to multimodal (gesture and speech) input for all stages of emergencies (planning, preparedness, response, recovery, and mitigation). The research reported here has already helped inform the design of the DAVE_G prototype gesture speech interface to a GIS. The design work focused on the support of un-tethered, gesture-speech access to GIS data displayed on a large screen. Large screens are important information display tools in Emergency Operations Centers as multiple people need to view the geospatial information at the same time to make collaborative decisions. For more in-depth discussion of the DAVE_G system see Rauschert et al. (2002); Cai et al. (in press); and MacEachren et al. (in press).

To develop an understanding of work in emergency management with geospatial information, I implemented a three stage, problem-centered study based on theoretical foundations in Cognitive Systems Engineering, Naturalistic Decision Making and Knowledge Elicitation. The knowledge obtained about current practices in these fields is used to create models and envisioned designs of advanced, next generation geospatial information technologies. Researchers in these fields have applied the theories and techniques to understand and support collaborative work in emergency rooms (Xiao, 2001), aircraft targeting (Perusich, 2001); and military command and control situations (Kuperman, 2001). To provide design assistance for the DAVE_G prototypes, this work focuses on gaining an understanding of the use of geospatial information during emergency response activities, with specific focus on hurricanes. Improved understanding is achieved by the production of models of crisis decision making and scenarios of the use of geospatial information during emergencies.

Major contributions of the research are as follows:

- provide an understanding of the process and geographic issues in crisis management through the creation of models and representations of response activities, individual and collaborative tasks, information requirements, and decision-making processes, and
- support the development of real world emergency response scenarios that serve as envisioned designs for more natural interfaces to GIS, new geospatial information technologies, and as representations of work in Emergency Operations Centers.
Developed scenarios provide the activity base that affords designers the ability to envision designs that can effectively and efficiently support cognitive and collaborative work. The following section describes the methodological approach adopted and defines and clarifies terminology.

1.2 The Problem Domain

A focus of this work is on learning how work is done in context, and then designing technologies according to a domain of practice as opposed to the more common, technologically centered design approach. The initial conception of emergency response activities during a hurricane for this project was based on the scenario in Figure 1.1.

![Scenario visualization](http://www.geovista.psu.edu/grants/nsf-itri/index.html)

The scenario was envisioned by the DAVE_G PIs as the conceptual basis for the types of activities that could be discussed in front of a large screen display during a hurricane evacuation.
Working from this initial conception, his research seeks to uncover an understanding of the problem domain: the nature of individual and collaborative work with geospatial information technologies during hurricane response, specifically, and emergency management, generally. This research addresses the use of GIS for emergency management to provide the breadth and depth of knowledge needed for building advanced interfaces and next generation GIS. Breadth is achieved by working with multiple agencies ranging from the county to national level to learn the different work strategies and constraints among multiple crisis management agencies. Depth is achieved through detailed focus with a single organization that has expertise in hurricane preparedness and response situations.

Cognitive Systems Engineering (CSE) research suggests that it is first necessary to obtain a detailed understanding of expert work within the domain of practice by conducting field work to design and build advanced technologies, such as DAVE_G, that until now have only existed as imaginative artifacts in movies and science fiction novels. The most common approaches to field studies are Cognitive Task Analysis (CTAs) (see Schraagen, et al. 2000 for several examples). Both cognitive and ecological constraints in the organizational environment form the basis for the design of adaptive, collaborative interfaces. A CTA is a study aimed at identifying and uncovering the specific cognitive processes, procedural skills and specific knowledge that individuals (and/or teams) apply to successfully and proficiently complete tasks. The specific fieldwork reported here is an ecological, problem centered Cognitive Task / Work Analysis, however for clarity, the term CTA will be used to describe the field work.

A CTA is generally the first stage in a larger, interdisciplinary and multi-year effort at understanding work in a domain of practice. The information collected during a CTA can be used for the creation of representative models and scenarios of work practices in the domain (such as emergency management) that also serve as envisioned designs for new technologies. These scenarios can be used for the design of prototypes (like DAVE_G) or to inform development of other collaborative tools related to coordination of activities, representation of geospatial information and tools for improving emergency management.

The CSE based problem centered CTA is adaptive, iterative, and opportunistic and is based on the Living Lab approach (described in detail in chapter 2) proposed by McNeese (McNeese, 2004). This approach to CSE builds on the traditions of naturalistic decision making, knowledge acquisition and elicitation, usability engineering, human computer interaction, computer supported cooperative work, and human centered GIScience. Above all, the approach emphasizes the importance of expert participation for improving understanding of
work, developing models and representations of work in context, and designing knowledge based technologies within the emergency management domain.

Most practitioners of CSE methods emphasize the role of models and representations. In Cognitive Systems Engineering, Vicente (1999) defines models and representations as a “description of a natural system [e.g. worker, work domain, domain of practice] using some type of formalism consisting of variables and the constraints between those variables.” These models and representations are abstractions used to simplify and describe the complexities of a natural system, a socio-technical system or domain of practice. This definition is adopted for this dissertation research and described further in Chapter 2.

The CSE approach followed is intrinsically iterative, with multiple feedbacks prompting moves forward and backward in the process as knowledge is obtained and technologies and prototypes are designed. The utopian ideal outcome of a CSE approach is to develop a ‘system of systems’ (building on Hollnagel and Woods, 1983; Woods, 1988) that provides responders and decision makers with unhindered communication and information access to solve all possible situations encountered in emergency management. This utopian ‘system of systems’ for emergency management would integrate people and technologies to allow untethered and unimpeded access to all forms of information (geospatial, damage estimates, resource locations, personnel distributions, etc.) for all persons involved in emergency response. Such a system should support first responders and decision makers from county, state, and federal level agencies whether they are distributed in the field or collocated in Emergency Operations Centers and command posts. The effort towards building such a system focuses on the iterative process of integrating expertise and knowledge into the design of advanced technologies.

In developing advanced decision support technologies, external factors often influence and alter the technology development process. Contributing factors include lessons learned from prototypes, shifting demands and needs of the work domain, and the addition of unforeseen technologies. These factors can shift development efforts into new areas of R&D that were previously unattainable or not even considered. With each incremental improvement to understanding the domain, model development, and the creation of envisioned designs about that future system, the goal of reaching an ideal system of systems is brought incrementally closer. The process of learning also has the potential to fundamentally alter the ‘ideal system,’ shifting focus to new visions for the utopian ‘system of systems.’

This CSE approach is highly participatory; domain experts assist with the creation of the work models, scenarios, and ideas about the effective design of the technologies. These experts serve as participatory designers rather than simply as informants to design better interfaces. To
develop the understanding of geospatial information use in collaborative emergency response efforts, representations and models of the work processes are co-created with experts. Initial results from early stages in the process can be used to help design early prototype systems. As more knowledge is acquired and models are built, the prototypes can be iteratively refined and adapted, building on lessons learned about the technologies and approaches that were successful, and those to avoid.

In discussing the design of similar complex systems, Zaff et al. (1993) point out that the user-centered design process is often hindered by the difficult task of eliciting domain specific knowledge from experts. Knowledge acquisition and elicitation techniques have been designed to help researchers learn and model an expert’s task knowledge. Systems designed without such expert knowledge are often prone to failure. Moreover, such systems might be highly usable, but actually represent the wrong solution for a given problem domain (Zaff et al., 1993). CSE addresses these issues through problem centered approaches steeped in domains of practice. The knowledge acquisition approaches are also human- or user-centered in that they seek to facilitate flexible access to information (open-ended questions and interviews), provide shared mediums for communication, and use procedures, such as concept mapping, that are compatible with the complex structures of work practices and the organizational structures of the human mind (Zaff et al., 1993).

Above, the general framework for the CSE approach was introduced. In order to put the ideas into practice for eliciting expert knowledge and modeling emergency management, I adopted a three-step approach. Step 1: Offsite Preliminary Cognitive Task Analysis; Step 2: Onsite Cognitive Task Analysis; and Step 3: Modeling the Domain (validation and design). Specific knowledge elicitation techniques include questionnaires, concept mapping with mission scenarios, and critical incident questioning. The representational strategies for modeling the domain include procedural concept maps, abstraction hierarchies, decision making diagrams and ladders, requirements specifications and scenarios of work.

1.3 Goals of the Dissertation
The primary goals of the dissertation, as discussed previously are:
• To develop a comprehensive understanding of how geospatial information and technologies are used in the domain of emergency management, with an emphasis on the use of geospatial information and technology and the relationship of the information and technology to collaborative decision making
• To inform and guide the development of a multimodal GIS for emergency management and response through the creation of scenarios and scripts of envisioned designs

Directly related sub goals include:

• To assess the applicability of a CSE approach for the complex problem domain of emergency management

• To build on previous work in CSE by developing a multistage methodological approach to knowledge acquisition for obtaining expert knowledge and transforming it into designs and models

• To explore the development of a more systematic approach for transforming elicited expertise into storyboard scripts

• To explore concept categorization through the application of a color coding scheme across multiple concept maps and timelines to study team collaboration and event response

1.4 Significance

1.4.1 Significance to Understanding Work with Geospatial Information

The use of Geographic Information Systems (GIS) has increased significantly over the past decade, yet many of the functionalities require detailed knowledge of arcane GIS terminologies. GIS, thus, remain difficult to use, and analysts and planners often do not tap the full range of advantages offered and tools provided by GIS (Schlaisich and Egenhofer, 2001). The development of new interfaces with a focus on system usability was identified as an important research goal for GIScience and geovisualization (Mark, 2000; Slocum et al., 2001). In order to improve access to geospatial information technologies and develop more usable interfaces, our understanding of the nature of work with GIS must be improved. The models of the domain developed and applied in this research are designed to improve understanding of work with geospatial information in emergency and crisis decision making situations. Specifically, they have the potential to contribute to several needs identified by Mark (2000): the development of ontologies and formal representations of geographic phenomena in terms of tasks and work, the development of cognitive models in GIScience, improvements to human interaction with geospatial information and an improved understanding of the societal impacts of geospatial information technologies. This research also has the potential to aid the design of geospatial information environments in decision making contexts, dynamic geospatial information representations of real time information, understanding of individual and group use of geospatial
information and the role of team and collaborative work with geospatial information, all issues raised by Slocum et al. (2001).

1.4.2 Significance to Group Spatial Decision making

Collaboration is critical to effective group decision making. This fact is especially true when considering time-critical decision making in situations such as command and control or emergency response. Substantial progress on understanding group decision making with geospatial information and technologies has been made in recent years (for reviews see Jankowski and Nyerges, 2001; MacEachren, 2000, 2001; MacEachren and Brewer, 2004, Jankowski et al. 1997 and Nyerges, 1999). Particularly significant is work in planning contexts (Nyerges et al. 1997, Jankowski and Nyerges, 2001). This research complements these efforts by considering and examining collaborative work in a new application domain and through the application of a new methodological approach (CSE) to understanding work in GIScience.

While it is recognized that multi-person collaboration is essential for effective decision making, our understanding of how large format printed and digital maps influence collaboration in practice is not well understood. In order to develop better large format displays, tools and interfaces to geospatial information that allow rich, collaborative interaction during time critical decision making; we must first learn how maps are used in collaborative, time critical situations now, and then project such designs into future technologies.

Gaining an understanding of how multiple people interact and collaborate during emergency response situations, and particularly, developing our understanding of the role of the geospatial information displayed in these situations is an important area of inquiry. Slocum et al., (2001) call for research that examines group work with geospatial information in order to determine the tools and interfaces that are required to support collaborative work on ill-defined tasks in geospatial decision making. This call was reiterated in an NRC report outlining the future of geospatial information use (NRC, 2003). Specifically, the NRC report called for an improved understanding of the use of geospatial information in a range of contexts from mobile access, collaborative interaction and decision making with geospatial information (NRC, 2003). The project reported here addresses components of these research agendas by studying collaborative teams in emergency management centers and by considering the communication between emergency responders (county, state and federal) during crises.

1.4.3 Significance to System Design

Designing new computing technologies like multimodal interfaces and collaborative virtual environments are two ways that researchers are attempting to overcome the barriers that
exist between decision makers and stakeholders and access by both to critical information. Several researchers (Oviatt (1997); Oviatt and Cohen (2000); and Sharma et al. (2001); Kettebekov and Sharma (2001)) have made significant contributions to multimodal interface design and development. Advanced collaborative displays with multimodal interfaces to geospatial information for military command and control were explored by Jedrysik et al. (2000) and by McGee and Cohen (2001). Despite these efforts, many research challenges remain for the design and testing of multimodal systems (see Sharma et al. (2003) for an overview). To support realistic interaction, prototypes need to be closely tied to actual world work with maps in decision making contexts. An expert-based, participatory design approach has the potential to significantly improve the computational methods required to recognize human intentions when requesting and manipulating geospatial information using natural speech and gesture. A key component of the approach applied here is the use of knowledge elicited during CTA activities to develop storyboard scenarios that characterize real-world practice. These scenarios provide one mechanism for discussing development strategies for multi-disciplinary design teams.

1.4.4 Significance to the GIScience

GIScience lacks a suite of methods for design and testing of interfaces to geospatial information (geovisualization environments, GIS, and other technologies). Slocum et al., (2001) and NRC (2003) suggested that a focus of geovisualization work should be on developing a methodology for examining the effectiveness of geovisualization methods applied to a wide range of tasks. Both reports emphasize that it is difficult to apply standard usability engineering principles to geographic problems because geovisualization methods often focus on work that involves ill-structured problems distributed over space and time. This research will contribute to this research agenda by exploring the utility of Cognitive System Engineering approaches for contributing to the design and development of gesture speech enabled interfaces to GIS.

This research is a unique contribution to understanding work with geospatial information and technologies by the adoption of the CSE methodology. To date, GIScience has tapped methods from Usability Engineering (UE), cognitive science and psychology, but has yet to consider the direct application of the comprehensive approach to technology development offered by CSE. Traditional usability studies, while highly applicable for improving previously designed systems, do not adequately address the design challenges posed for developing next generation technologies and interfaces to geospatial information.

A key element for effective approaches to developing new technologies is to consistently adapt and refine the design processes. This practice of adaptation and refinement has been referred to as the ‘double loop paradigm’ (Buttenfield, 1999). (Within CSE, in reference to
Cognitive Task Analysis, Potter et al. (2000) present a similar idea defined as ‘Iterative Bootstrapping.’) These iterative approaches are crucial to the long-term development of methods for studying work and improving Human Computer Interaction. The spatial focus of geographers will possibly lead to spatially-tailored knowledge elicitation and representation techniques that deal with the complexities of work (such as collaborative spatial decision making) distributed over space and place.

1.4.5 Significance to Cognitive Systems Engineering

CSE is an interdisciplinary field that incorporates multiple, loosely coupled ideological perspectives. Building on a review of the CSE literature, this research attempts to simplify the process of conducting Cognitive Task Analyses through a simplification of the overall process and application of specific techniques used to elicit experience and expertise. Emergency management is distributed, is time-critical, is resource intensive, has ill-defined situations, contains high degrees of uncertainty and has deep social and institutional constraints making it an appropriate choice for the application of a problem centered approach in the CSE tradition. Moreover, lessons learned while studying the complexities of such domain constraints have the potential to improve the development of new CSE techniques to studying work.

This research contributes to what Potter et al. (2000) refer to as the common goal of all such approaches, to identify ways to improve interfaces and technologies so that they in turn improve team and individual performance. Such approaches focus on improving and developing an ongoing understanding of participants, artifacts, and technologies within specific domains of practice. As researchers develop an understanding of multiple domains by modeling the structure and processes of work, they can iteratively step back and look at the underlying, universal patterns that appear across domains. By studying emergency response generally and hurricanes specifically, this research has the potential to inform the design of command and control systems for the military or those in an air traffic control centers. Also, by using experts as participatory designers, the research also can help inform the design of new collaboratively enabled technologies. Finally, this research will help improve our understanding of concept mapping techniques by exploring new methods for eliciting and representing knowledge on procedural concept maps.

1.5 Products of the Dissertation

Results from this study include the following seven products:

- Models that depict functional, procedural and decision making activities during work with geospatial information and technologies in emergency management at the federal, state and local levels
• Storyboard scripts that depict emergency response efforts during emergency response planning, preparedness, response, recovery, and mitigation
• Lessons learned from implementing a CSE approach as a means for studying issues in geography
• Comprehensive understanding of group work with geospatial information and technologies in hurricane management
• A general understanding of group work with geospatial information and technologies for emergency management
• An improved understanding of temporal issues involved in decision making activities with a geographic focus
• Augmentations to existing knowledge elicitation techniques for application to problems in geospatial, collaborative decision making and for studying teams

1.6 Structure

This chapter has identified the problem domain and introduced the topic of the dissertation. Chapter 2 reviews the methodological and domain-specific literature related to the dissertation. Chapter 3 presents the three-stage methodological approach undertaken to study work with geospatial information in emergency management and introduces the specific methods used in this dissertation. Chapter 4 presents the instantiation and results from Stage I: Offsite Preliminary Cognitive Task Analysis. The steps that led from a broad goal of conducting research in emergency management and GIS as a whole to a more narrow focus on hurricane response specifically are presented and discussed. All offsite data collection results are discussed and the influence of Stage 1 findings on Stage II is presented in Chapter 4, as well. Chapter 5 outlines the design for Stage II: Onsite Cognitive Task Analyses. Several traditional knowledge elicitation techniques were woven into a strategy for eliciting knowledge (tacit, experiential, explicit, procedural, etc). This research builds on a program (originally developed by Zaff et al. (1993)) for eliciting such knowledge and incorporating that knowledge into designs that describe how to integrate multiple converging techniques into an appropriate knowledge elicitation and systems design program. Here also, information on elements of the process that did not work as planned are presented and discussed in relation to their impact on the Stage III: Modeling the Domain, which is introduced in Chapter 6. Chapter 6 presents the process of data validation and system design as well as the results and models created from knowledge elicited in Stages I and II. Chapter 7 focuses on scenario development and the creation of summary and storyboard scripts. These scripts merge aspects of theatre and drama into the design of the final script which can then be used as a guideline for prototype development. The process through which the knowledge elicitation techniques are used to create these storyboard scripts is outlined and discussed. Finally, sample scripts are presented. Chapter 8: Conclusions and Future Work, presents contributions of the dissertation and the implications of this research within the context
of GIScience, HCI, multimodal systems and CSE. Refinements to the overall methodological approach and lessons learned from the implementation of the process are also discussed. Finally, possible future research is discussed and presented.
Chapter II
Review of Literature

“Read not to contradict, and confute; nor to believe and take for
granted; nor to find talk and discourse; but to weigh and
consider. Some books are to be tasted, others to be swallowed,
and some few to be chewed and digested: that is, some books are
to be read only in parts; others to be read but not curiously; and
some few to be read wholly, and with diligence and attention...”

--Francis Bacon, "Of Studies"--
2.1 Introduction

For too long, software and technologies have been designed for technology’s sake. This “if you build it they will come” approach has led to the development and proliferation of a range of unused or unusable technologies. Businesses (often driven by money, investors, market forces, providing yearly support through returning customers and building new clientele) and academia (driven by the development of demos for funding agencies, publications, and the need to fulfill grant requirements through publications and presentations at professional meetings) both contribute to the proliferation of unusable technologies.

Blame need not be assigned to any party, especially when unpredictable outside forces (new technologies, funding sources, and vocational deliverables) have a marked influence on software development. Instead, an improved understanding of mechanisms for the technology builders and users to collaboratively construct designs that reflect how humans work, how they perceive their environment through vision and cognition, how humans communicate through voice, gesture and body language, and how they collaborate and cooperate through team work is needed. Moreover, efforts to couple computing systems with the user’s cognitive organization, visual abilities, perception of motion, as well as capabilities to abstract spatial properties (visualizing the real world through two dimensional map based displays) are also important.

This chapter emphasizes the importance of ‘problem context’ in designing tools (a tool can be any device used for work ranging from pencil and paper to hi-tech computing environments). The ecological context of work includes the domain of practice, the work practitioners, and the spatio-temporal aspects within which work is conducted. Ecological factors influence individual and group cognition, and thus, it is important to understand the interplay of those factors. The contention is that when the real world context of work is ignored, efforts (such as knowledge based technology design) suffer, prompting a need to discover and develop new ways for understanding domain practitioners, their world, and the tools they use to interact within that world. Through this improved understanding, new tools and work practices can emerge that eclipse and transcend the traditional methods of work.

The strategy of building technologies according to work is not a new idea, and the following sections will illustrate efforts aimed at achieving this end. GIS software technologies have become easier to use in the past decade, but GIS still require substantial training to use and interfaces are far from being natural and intuitive, hindering the reach, utility, and usefulness of geospatial information. This point is especially vital when dealing with decision making contexts for crises and emergencies. Decision makers often have short temporal windows in which they must weigh all possible evidence (including maps and GIS outputs), synthesize that evidence, and
issue protective action recommendations. It follows that the easier an interface to a map based system is to learn and to use, the more quickly the decision maker can transform geospatial data into contextual information and thus, make informed decisions.

The first sections in this chapter review methodological approaches to study and understand work and expertise. Specifically, an overview of methodological literature is presented followed by a detailed section on the developments and approaches in CSE. Following that section is an overview of expertise, knowledge, and knowledge elicitation as it relates to CSE and the approach of the dissertation. The chapter concludes with a review of GIScience literature related to the dissertation’s problem context: GIS and decision making. The section highlights the important interface issues that hinder effective collaborative decision making with GIS in emergency management. In the following section, fields that study the design of technologies are reviewed and specific emphasis is placed on characterizing and distinguishing the methods and techniques of Cognitive Systems Engineering.

2.2 Overview of Methodological Literature

A loosely coupled, and sometimes disparate set of fields have contributed to the development and evaluation of human interaction with computer systems. Human Engineering is an interdisciplinary activity that has been around for several decades (McCormick, 1957). Human engineering can be considered engineering for human use, and has been referred to as biomechanics, engineering psychology, applied experimental psychology, human factors and ergonomics. The goals of human engineering are primarily centered on efficiency of work activities (McCormick, 1957). An emergent field in this area is known as human factors. Human factors studies have traditionally focused on physical ergonomics, interface design, and documentation and training; see Turk (1993; 1995) for overviews of human factors and human computer interaction in relation to GIScience. These fields of study, in part, contributed to the field now known as Human Computer Interaction.

The HCI community is primarily concerned with developing computer systems that were designed by taking into consideration the ways that humans think and operate. Human factors analysis (also known as ergonomics) has been defined as:

“the study of how humans accomplish work-related tasks in the context of human-machine system operation and how behavioral and non-behavioral variables affect that accomplishment. Human factors is also the application of behavioral principles to the design, development, testing, and operation of equipment and systems (Meister, 1989, 2).”
Figure 2.1 attempts to trace the development of disciplines (such as those described above) that build technologies and computer applications, demonstrating how they are intertwined today. As this diagram shows, the connections and intertwining of fields that have contributed to or are developing advanced technologies are quite complex. One pathway into the central portion builds on industrial psychology, human engineering and human factors engineering. Another pathway flows from cognitive psychology and cognitive science. Computer science is a third pathway towards the center of the overlapping fields.

The overlap and placement of the circles could be debated endlessly, therefore, this diagram should be viewed as one of many potential representations that tries to show: a) the difficulty in distinguishing among these fields b) the dynamic relationships among the fields of
study c) the fuzziness of the boundaries where one field of study begins and another field ends and d) the high degree of overlap among disciplines. For example, Computer Supported Cooperative Work, Human Computer Interaction and Usability Engineering have significant overlap with Cognitive Systems Engineering. The following sections compare and contrast two complementary disciplines on the diagram, Cognitive Systems Engineering and Usability Engineering.

### 2.2.1 Introduction to Cognitive Systems Engineering

CSE, at the center of the diagram, is emerging as a dominant focus of study. CSE is aimed at design of interfaces (not limited to computers) between the decision maker and the deep relational structure of the work space (Rasmussen, 1998). Thus, in CSE, focus is placed on methods of representing expertise that has been elicited during naturalistic studies of work and then incorporating that expertise into designs. The designed systems would not have to be a single software application, but instead multiple technologies used that improve the management of information flow within the organization, the communication between workers, and all other aspects of work within that domain. Specific computer technologies might comprise one component of this larger system. It is important to note that practitioners of CSE study first the system or domain of practice and subsequently develop designs for individual technologies to augment and improve the work conducted within the system. Vicente (1999) refers to the system or domain of practice as a socio-technical system. This approach is important because, as Hollnagel and Woods (1983) and Woods (1988) point out, whenever new technology is injected into a system, the system must fundamentally adapt and change – and often, systems (such as an organization) are not receptive to such technological interventions. The inflexibility of the system and the work practices can create situations where even the best designed piece of technology is not used because it was developed for a different work activity or in a different work context. Thus it is very important to understand the entire system being augmented.

Cognitive Systems Engineering is also concerned with how expert knowledge can be transformed into an envisioned blueprint (or design) that represents a hypothesis about how the design influences cognition or collaboration. Cognitive systems engineering methods aid analysts in the discovery of the cognitive processes that underlie the task for which a system was designed (after McNeese 2004; Hollnagel and Woods, 1983). Therefore, essentially, CSE is concerned with coupling human intelligence and cognition with machine power into integrated systems that maximize overall performance (Woods and Roth, 1988; Woods, 1988). For more specific treatments of CSE, see Rasmussen (1998) and Hollnagel and Woods (1983).
2.2.2 Introduction to Usability Engineering

Another prominent field developing tools, technologies and computer systems is UE. Before designing a new tool or technology, in order to understand the users, their tasks, and their working environment, usability engineers talk to users, observe them work with existing software, and ask them questions to understand the user characteristics and system features they need, etc. Related to computers specifically, UE is often used during the requirements analysis or early design stage of software development and is often the first step of usability work for a project (Neilsen, 1993). UE practitioners have developed suites of methods to collect, test, and verify the design of software and interfaces in order to learn about how humans interact with computer systems, and to test the designs that result from a human centered system perspective. These methods, referred to collectively as usability evaluation methods consist of three large categories: usability inquiry, inspection, and testing (Nielsen, 1993).

Usability inquiry methods are aimed at obtaining information about the users' likes, dislikes, and needs through a series of interviews, informal discussions, and on-site observation (Nielsen, 1993). Field observation, focus groups, interviews, user logging, proactive field studies and questionnaires are all usability inquiry methods (Nielsen, 1993).

Usability inspection is a label applied to a set of methods that are based on having evaluators inspect or examine usability-related aspects of a user interface or a physical device. Usability inspection methods are intended to help evaluate user interface designs. Mack and Nielsen (1994) argue that a defining characteristic of inspection methods is the reliance on judgment as a source of design feedback for specific elements in a user interface. Examples of usability inspection methods include heuristic evaluations and guidelines based reviews (experts judge and rate the system based on established guidelines), and cognitive walkthroughs (evaluators work through several tasks and evaluate the ease of understanding and usability of the interface).

A usability engineering (UE) approach focuses on the design of the actual, physical implementation of the human computer interface (thus encompassing many of the usability inquiry and inspection methods discussed above). Usability engineering often focused on developing and testing an interface’s ease of use, efficiency, error handling, and obtaining information about user satisfaction. Such approaches were developed to improve the process of commercial software design. See Nielsen (1993) and Shneiderman (1998) for comprehensive overviews of UE techniques for interface design and Gabbard et al. (1999) for an implementation of usability engineering in the development of virtual reality visualization environments.
In Usability Engineering, an initial approach called a proactive field study is concerned with conducting field work to learn about the technology (technology-centric) being used to achieve tasks, who the users are, what kind of locations they work in, and how they would use the new technology being developed to achieve specific, isolated tasks (e.g. produce a map of flooded regions within Texas). The fieldwork for this kind of study focuses on the user first, and then considers the larger context within which tasks comprise work and includes: 1.) identifying individual user characteristics, 2.) task analysis, 3.) functional analysis, and 4.) user and task evolution. A distinguishing factor here is that UE approaches are largely technology specific and user centric and not aimed at modeling and understanding larger systems such as the work domain or decision making processes within the system.

2.2.3 Comparing and Contrasting CSE and UE

CSE and UE are emergent areas of research and practice that have risen to prominence. Researchers and developers from diverse research domains (like GIScience) have begun to draw on them. These two approaches to technology development are fundamentally complementary, and if used together, have the potential to improve the design of computing systems. However they are not often employed in a complementary fashion and researchers instead choose one approach over the other. In general, UE approaches tend to be techno-centric and CSE approaches are work or problem-centric. The terms user-centric or human-centered are also often used to describe the approaches as they are attempts at developing better systems and technologies for humans.

Although usability engineering and cognitive systems engineering approaches to system design have a somewhat different focus, the approaches are both aimed at improving technologies that humans rely upon for work. When designing new systems, researchers and developers could benefit by adopting design strategies that maximize the usefulness of both types of engineering approaches. A CSE approach can help designers first develop an understanding of work, and thus, produce better designs. And UE methods can then be used to improve the usability of the systems implemented according to those designs. The critical distinction between CSE and UE is that CSE attempts to gain an in-depth understanding of the social, structural, procedural and cognitive aspects of work, while usability engineering tends to be more concerned with testing the usability of specific products or interface components. A useful way of examining the interdependencies of the two is that a CSE approach is most useful at the formative stages of development, and is especially important for dealing with situations where the tasks and goals of the system are ill-defined and emergent, whereas a UE approach would be most useful with well established and clearly defined goals and tasks. Therefore, CSE aids in developing an
understanding of the process of HCI interaction for a given task, and guiding the design of the interface. Usability approaches (with a testing focus) are best implemented when system interface prototypes have been built, and actual user testing is required to assess the usability of the interface. A system designed with only usability testing might be extremely useable, however, because there was no initial knowledge elicitation from domain experts, models of current work, or incorporation of the actual structure of complex social and organizations constraints into the design, it could be a case of having the wrong system, designed correctly (Woods, 1998). The reverse, however, would also be true. A CSE approach could elicit expertise and present that information as models of work, yet the result could yield only envisioned designs and prototype specifications and no physical product to actually test and evaluate. Generally, the result is a physical prototype, but the first iteration in a CSE approach is often inadequate since no CSE product produces perfect models of work and of the potential impact on work of a device that does not yet exist. Therefore, it takes multiple iterations of a CSE and UE approach to achieve successful prototype designs.

2.2.4 Qualitative Research Approaches

Before proceeding with a review of CSE approaches, it is important to note that many of the methods (particularly knowledge elicitation methods) that are used for understanding work are similar to, or were developed from techniques in the longer tradition of qualitative methods of ethnography and anthropology. Most approaches to understanding work (CSE, Naturalistic Decision Making, Work Analysis, and CTA) for designing tools and technologies (CSCW, UE, HCI) borrow and build on ethnographic techniques. For example, in anthropological ethnographic studies, researchers often immerse themselves within the region of study, becoming part of that culture. Studies of work (or workers), similarly, often take place on site, but it is often impossible for a researcher to become part of the work ‘culture’ that they are studying. Nevertheless, there are similarities between Cognitive Task Analysis methods used in CSE and ethnographic techniques and approaches to research that have similarities with.

Creswell (1997) identifies and describes five different types of qualitative studies (each with specific methods and approaches for data collection and presentation of results). For example, biographical approaches are for studying individuals; ethnographies are a means for studying a cultural group, a phenomenological approach focuses on a concept or incident, a grounded theory approach presents and/or attempts to refute a theory, and a case study approach focuses on studying a specific system (Creswell, 1997). Of these traditions and methods, ‘ethnographies’ and ‘case studies’ are particularly similar to the methods in CSE and are discussed in the following sections.
According to Creswell (1997) an ethnography is aimed at describing and interpreting a cultural and social group using techniques from cultural anthropology and sociology. An ethnographer conducts observations and interviews with the group being studied, collects artifacts, and often spends a time of six months to a year doing so. The results are produced in descriptive narrative form that includes the ethnographer’s analysis and interpretation (Creswell, 1997). Similarly, case studies are aimed at developing in depth analyses of specific systems, bounded by space and time. The origin of this approach comes from political science, sociology, urban studies and other social science disciplines. In a case study, a researcher seeks to develop an in-depth analysis of single or multiple cases wherein a case can be a person, an event, an activity, a problem, etc. Creswell (1997). Like ethnographies, case studies involve multi-source data collection strategies (e.g. gathering documents, archives, interviews, observations as well as physical artifacts Creswell (1997)). Typically, case study results and analyses are presented in descriptive form where the researcher makes assertions about observed situations based on themes identified in the research (Creswell, 1997).

An important part of qualitative research is triangulation. Triangulation is an attempt to instill rigor in the methods and approaches to qualitative research through the use of multiple sources, methods, investigators and theories. An important factor for instilling rigor, Hay (2000) notes, is documentation of the research and full disclosure of where the initial interest developed and a description of the purpose for conducting the study. These issues are equally important in CSE strategies (though not always followed), and should be considered by the researchers who employ them.

2.3 Developments and Approaches in Cognitive Systems Engineering

Cognitive Systems Engineering methods have developed to incorporate rapidly changing computer and information technologies into an overall system oriented view. The development of new technologies can cause significant shifts and alterations to the roles and activities of humans. For example, the tasks for which individuals are responsible can shift from complete control to supervisory control – such as system monitoring and management – thus, increasing the individual’s cognitive load (Woods and Roth, 1988). Technological advances do not always enhance performance. Systems designed with the wrong specifications, or for the wrong reasons can actually hinder performance. Adding collaboration into the mix only exacerbates the situation.

CSE approaches are concerned with the interplay among all of the interfaces within complex, socio-technical systems this contrasts with traditional interface design approaches that focus on a single interface to one technology. CSE is not only concerned with human-computer
interaction, but with the interaction amongst all available technologies and people. Rasmussen (1998) calls this focus on multiple interfaces Ecological Interface Design (EID).

CSE is an amorphous and emerging field, and like many of the systems that CSE researchers study, it is not very well documented and organized. Eggleston (2002) provides an overview of the theoretical foundations upon which CSE strategies progressed, distilling four genotypes from which research in CSE evolved since the early to mid 1980s. These four are broken down according to the institutions where the major practitioners were developing the theories and methods of CSE: Carnegie Mellon University led by Stuart Card, Ohio State University led by David Woods, RISO National Laboratory in Denmark led by Jens Rasmussen and the University of California at San Diego led by Donald Norman.

Eggleston identified the core elements of the Carnegie Mellon University genotype as focused on work as a cognitive activity and the development of a modeling framework for the representation of mental activities involved in tasks. The Ohio State University genotype is described as being focused on studying humans working with tools and the nature of problem solving in work. Eggleston (2002) describes the RISO genotype as primarily focused on problem solving and decision making and the creation of a framework to guide system development that is robust in its error handling capabilities. The fourth genotype at UCSD was differentiated from the other three by focusing more on work at the level of interaction between humans and computers (essentially UE). This genotype focused on describing the relationship between the physical system (the computer) and the psychological system (the users). To summarize, the CMU genotype is focused on cognitive modeling of tasks, the OSU genotype on problem solving work with tools, the RISO genotype on decision making and error handling and the UCSD genotype on computers and users. The diversity of approaches in CSE, and their interconnections makes distinguishing one from another a difficult task.

2.3.1 Appropriate Domains of Study for CSE Approaches

The investment in time and resources means that not all application domains or even technology development efforts are appropriate for conducting CSE research. Vicente (1999) argues that the level of study should be complex socio-technical systems (an example would be emergency management). In fact, Vicente (1999) outlines eleven features that researchers should consider to determine whether or not the system being studied is appropriate for a CSE approach. The factors that contribute to the complexity of socio-technical systems are 1.) large problem domains, 2.) social aspects – the number of people required to make the system work, 3.) heterogeneous perspectives of the social network, 4.) distributed team members, 5.) dynamic situations, 6.) potential hazards, 7.) coupling – high degree of interaction, 8.) automation, 9.) data
uncertainties, 10.) mediated interaction, and finally, 11.) likelihood of disturbances and unanticipated events. While a system need not meet all of these criteria to be appropriate for a CSE approach, the researcher should examine the system of study based on these factors before selecting methods, model representations and knowledge elicitation techniques.

CSE techniques can be used to examine multiple levels of complex socio-technical systems (see Figure 2.2). This diagram depicts that a CSE strategy needs to focus on not only the technical system, but the workers, organizational structure and the environmental context of the work domain. This ecological approach is built on the traditions of CSE work begun by Rasmussen (1986). The capabilities and limitations of the workers, the organizational and management constraints, and the overall working environment (laws, regulations, and physical environment) all contribute to the complexity of socio-technical systems and should be examined in relation to their influence on work (Vicente, 1999). Once CSE is determined to be an appropriate ideological approach, the researcher needs to begin selecting the CSE framework to follow. One way to stratify the methodological approaches is based on the models that the procedures produce.

### 2.3.2 Models in Cognitive Systems Engineering

Rather than attempting to identify all of the dissimilarities in CSE, a focus on similarities has the potential to provide insight into the nature of the domain. The components of all cognitive systems engineering studies are 1) analysis of work and 2) representation of that analysis through models of the work processes. CSE is aimed at improving tools and technologies by first understanding the context of work. To develop a comprehensive understanding of work, one must study not only the individual worker and the worker’s specific tasks, but also study the socio-organizational environment within which the work is conducted, the tasks that are conducted and how they are carried out. The understanding of the domain is expressed through abstractions of the work domain via models and representations (defined in Chapter I and presented in detail in Chapter VI).
There are two complementary components in an ecological, human centered cognitive systems engineering approach to understanding work. The first is the methodological perspective which is concerned with the process of data collection methods that comprise a cognitive work/task analysis, and the second is a conceptual perspective that is largely concerned with the specific use of the collected data in modeling and representation techniques (See figure 2.3). Selection of techniques influences the type of model that can be created and the selection of desired models influences which techniques provide the appropriate data to model.

CSE researchers are beginning to converge on a common approach in that the CSE practitioner first decides what products (models or representations) are desired, and then those models will dictate which specific knowledge elicitation techniques to select and apply. Those techniques provide the data (knowledge of work) that are needed to populate and represent that knowledge through CSE models.

Figure 2.3: Data Collection and Modeling / Representation
adapted from Vicente, 1999

Vicente (1999) developed a characterization of CSE studies that stratifies the approaches according the representations and models that the approach yields. He identified three generic categories: 1) normative modeling approaches (describe how a system should behave), 2) descriptive modeling approaches (demonstrate how systems actually behave, and 3) formative modeling approaches (specify requirements so the system can behave in a new way) (Vicente, 1999). In the following sections, these three approaches are discussed in terms of the
relationship to the theoretical foundations of the approaches that apply them. Vicente’s goal was to advocate an integrated framework for studying work that borrowed the advantages of Normative and Descriptive approaches and merged them into a new approach to studying work: a formative approach.

2.3.2.1 Normative Approaches

Vicente (1999) argues that normative approaches legislate work by producing models that prescribe how a system should behave. He considers Cognitive Task Analysis, Task Analysis, and Goals, Operators, Methods, and Selection Rules (GOMS) as prolific examples of normative methods or approaches for studying systems that provide input to the creation of normative models. Task analysis methods are used to identify the tasks that users must perform in order to achieve a goal and then presented as models of the actions and cognitive processes required to complete those tasks (Vicente, 1999).

A CTA attempts to uncover the nature of work, identify specific tasks and strategies required to complete the tasks and to characterize the cognitive and collaborative requirements for completion of that work. Computers and technologies increasingly complete procedural and predictable tasks (monitoring gauges, updating software, running statistical procedures). A shift in the nature of human work increases the complexity of cognitive processes required to support work. Specifically, Woods (1998) describes CTA as an examination of a field of practice in which a researcher focuses on 1) the agents or individuals, 2) the world or environment within which they work, and 3) the tools or artifacts used to interact with the surrounding environment. Potter et al. (2000) advocate the application of CTA early in the development of any large technological development. Vicente (1999) suggests CTAs can be distinguished from other techniques based on their primary focus on uncovering the tasks required to complete a given goal.

A problem-centric CTA places emphasis on the decision making activities of work in practice, and is, thus, closely aligned with research in Naturalistic Decision Making described below. A CTA might begin with a goal or problem (e.g. prevent destruction of human life and property in emergencies), move to a specific problem situation (e.g. earthquake response and recovery) and then seek to uncover the tasks required to solve the problem and meet the goal. To identify each of these elements, the CTA practitioner often uses Knowledge Elicitation techniques in an opportunistic, adaptive manner. The elicited expertise is modeled into representations of work and reified through scenarios of use and eventually design prototypes (integrating CSE and UE methodologies). Then, the information gleaned from initial analyses becomes a baseline condition of domain understanding within that problem context. Participatory
design and collaboration with experts as designers remain key elements in the problem centered approach. Often, during KE exercises, new problem contexts in the work domain are uncovered, thus becoming the focus of the next round of elicitation sessions during the next stage of work analysis. The models produced during multiple iterative, opportunistic CTAs to understand a work domain are similar to the goal of a comprehensive Cognitive Work Analysis (described as an formative modeling approach and advocated by Vicente (1999)) with an initial Work Domain Analysis (WDA) being the first stage in developing an understanding of the domain.

2.3.2.2 Descriptive Approaches

According to Vicente (1999) descriptive approaches and models portray and describe how systems behave in practice. These observation-based approaches seek to understand how the workers actually behave by conducting field studies documenting the challenges that workers face in the real world. A descriptive model documents current work practices and bases new design suggestions on the individual understanding gained from observation (Vicente, 1999). Vicente places research in Naturalistic Decision Making, Situated Action, Distributed Cognition and Activity Theory as directly relevant to this category.

Naturalistic Decision Making emerged in the late 1980s, and is aimed at understanding how people use experience to make decisions in the field (Zsambok, 1997). Researchers in Naturalistic Decision Making do not distinguish between the study of individuals or groups, and instead focus on studies in dynamic, uncertain and fast-paced environments where the stakes are high and require workers to consider factors outside of their own role in the process from a holistic perspective. For comprehensive treatments of Naturalistic Decision Making research see the edited volumes by Zsambok and Klein 1997) and Salas and Klein (2001). Naturalistic Decision Making is not concerned with developing specific technologies or systems, but instead with understanding decision making situations.

2.3.2.3 Formative Approaches

Citing limitations in the Normative or Descriptive modeling approaches to understanding work, Vicente (1999) argues for a Formative approach that focuses on the technological and organization requirements that are needed to support work effectively in a complex system. Vicente (1999) distinguish Formative approaches from Normative and Descriptive in that the models produced seek to specify the requirements that must be satisfied so that a system can behave in a new, desired way.

CSE is ripe with confusing terminologies. Vicente (1999) sought to clearly define terms related to his formative approach for studying work, defining work analysis as any technique for
analyzing human work (specific examples include Task Analysis and Work Domain Analysis). Work Domain Analysis (WDA) is the first of five stages in Vicente’s (1999) framework of Cognitive Work Analysis that focuses specifically on identifying the functional structure of a work domain. Thus, a Cognitive Work Analysis for understanding emergency management would begin with knowledge elicitation aimed at modeling the work domain by using abstraction hierarchies (described below). The fundamental goal of Cognitive Systems Engineering as related by Vicente (1999) and Rasmussen et al. (1994) emphasizes Work Analysis by following a prescribed framework (called Cognitive Work Analysis) and using explicit techniques in a specific order (for example stage 1 is Work Domain Analysis (WDA)).

CWA consists of working from the whole domain down to the individual workers by first studying 1) work domain, 2) control tasks, 3) strategies of work 4) social organization, and 5) worker competency. Specific Knowledge Elicitation and CSE modeling techniques are applied within each of the prescriptive stages (CWA is described in detail below).

2.3.3 Examples of CSE Models and Representations

Cognitive systems engineering provides frameworks studying work (introduced above and discussed later) as well as systematic methods for understanding the work domain based on information elicited from domain experts (McNeese et al. 1999; Rasmussen, 1998). The following three subsections discuss some of the tools and representations used for modeling knowledge about work.

2.3.3.1 The Abstraction Hierarchy

Rasmussen’s work is considered a seminal achievement in the emergence of Cognitive Systems Engineering. Rasmussen (1986) presented an approach for studying a domain of practice, the foundation of which is the abstraction hierarchy. Rasmussen’s work was developed based on his research related to the engineering design of supervisory control systems in industrial processing plants (Rasmussen, 1986). The research was aimed at analyzing risk and developing reliable systems for industries such as nuclear power and chemical processing. When Rasmussen began the work in the 1960s, the technical demands of supervisory control were shifting from mundane tasks to complex supervisory situations requiring the system operator to monitor multiple gauges, incoming verbal reports, and information related to the smooth operation of the facility. This form of work in these supervisory control rooms was increasing the cognitive load on the operators.

The abstraction hierarchy is a way of studying and representing the functional properties of technical systems (Rasmussen, 1986). An overall design structure of this representation technique is presented in Figure 2.4. Rasmussen (1998) refined the abstraction hierarchy into the
abstraction decomposition hierarchical space for representing the results of work analysis. Along the top of the 2D representation, decomposition of the work domain is achieved by examining ‘whole-part’ relationships ranging from global to the more elemental elements of the domain (Vicente, 1999). As Vicente (1999) explains, by moving to the right, one essentially zooms in to a more detailed view of the system.

![Whole Part Decomposition](image)

**Figure 2.4: Whole Part Decomposition (Rasmussen, 1998)**

The vertical axis of the representation depicts the ‘means-end’ relationship of the domain as an abstraction hierarchy. The upper levels in the hierarchy describe why something is done (the abstract means), and the lower levels depict how it is done (the concrete end) (Vicente, 1999). The levels within the hierarchy are generally altered by individual practitioners using the representation to satisfy their own specific goals within a single domain. Not all practitioners use the whole-part decomposition, and instead focus only on the mean-ends relationships. A detailed set of the means end levels is presented in figure 2.5 based on Rasmussen’s original ideas.
Figure 2.5: Rasmussen’s Original Abstraction Hierarchy (Rasmussen, 1986)

<table>
<thead>
<tr>
<th>Functional Purpose</th>
<th>production flow models, system objectives, constraints, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract Function</td>
<td>causal structures: mass, energy, and information flow topology, etc.</td>
</tr>
<tr>
<td>Generalized Functions</td>
<td>&quot;Standard&quot; functions and process feedback loops, heat transfer, etc.</td>
</tr>
<tr>
<td>Physical Functions</td>
<td>Electrical, mechanical, chemical processes of components and equipment</td>
</tr>
<tr>
<td>Physical Form</td>
<td>Physical appearance and anatomy, material and form; locations, etc.</td>
</tr>
</tbody>
</table>

The abstraction hierarchy is primarily used as a means for structuring knowledge. The hierarchy helps develop an understanding of the interactions between the high level goals (functional purpose) and the low level physical tools that achieve those goals (physical form). At the top of the hierarchy are the goals of work in the system at an abstract level. By moving further down the hierarchy, the focus switches to the physical implementation that is used to accomplish the functions at the higher levels. Most CSE studies of work seek to extract the information about a domain and construct the abstraction hierarchy; another tool that is used to examine work is the decision ladder.

2.3.3.2 Decision Ladders

Decision ladders are a representation strategy that practitioners use to help to understand the decision processes (or control tasks) between actors and the system (i.e. humans and computers) (Rasmussen, 1998). The decision ladder represents a template or a ‘map’ upon which decision making processes can be modeled and structured; Vicente (1999) describes the decision ladder as a ‘skeleton without flesh.’ As Vicente (1999) points out, the decision ladder is a tool that is intended to identify WHAT needs to be done for a given task.

A key component of decision ladders is that they do not represent tasks and decisions linearly, but instead focus on the interaction between different types of information processing activities involved for a given decision (such as data and information collection, and analysis of alternatives). This type of representation is important for studies of experts. The decision ladder can help identify when an expert has tapped their knowledge of the decision space based on heuristics and shortcuts allowing associative leaps to task execution. An example of the decision ladder representation appears in figure 2.6. The boxes represent the information processing activities for a given decisions or processes and circles represent the current state of knowledge. This hierarchy was originally developed for process control plant design (Rasmussen, 1986).
Abstraction hierarchies and decision ladders are two methods for building and constructing models of work in practice. Vicente (1999) describes the relationship as: abstraction hierarchies describe the functional system being controlled, and the decision ladders describe the
information processing activities required to complete tasks to control the system described on the abstraction hierarchy. Another form of representation that captures both elements of the work domain as well as the control tasks required within the domain is a concept map, discussed below.

2.3.3.3 Concept Maps

A concept map is a representation of individual concepts and their contextual relationships. Concept mapping is a modeling tool that is also a knowledge elicitation technique. Concept maps are used for 1) facilitating unobtrusive information transfer through a shared medium, 2) identifying key ideas, 3) providing a formalism analogous to the mental organization of the expert (semantic, non linear), and 4) summarizing a given cognitive domain (McNeese et al. 1990). To put it simply, concept maps allow individuals to see what other people are thinking (Fisher et al, 1989). Concept maps can be displayed or represented differently (with or without timelines, hierarchically, etc). Figure 2.7 uses a concept map to describe the representation technique and the process of concept mapping. Concept maps are produced during interviews and yield a graphic representation of the interview upon completion. Concepts are represented as ovals and the relationships between them are indicated by the labeled arrows.

Figure 2.7: Concept Mapping Example
There are alternative representation strategies for representing or ‘mapping’ concepts, relationships, activities, ‘states’, concepts, and data. Such approaches often have formalized structures that can make their use as a knowledge elicitation method problematic. However, these representations can communicate system design features to those familiar with the techniques better than a concept map representation. These techniques include state diagrams, task charts, data flow diagrams, data diagrams, structure charts and the Unified Modeling Language. See Sommerville (1989) and Constantine and Yourdon (1979) for descriptions of these structured design methods. Zaff et al. (1993) employed a more structured technique, IDEF-0, and found that the formalized structure altered the way the experts thought about their domain, and thus, changed the information they communicated to the knowledge elicitor. Specifically, while working with pilots, Zaff et al. (1993) report that the participants indicated that they focused their discussion on evaluating the existing model and its solution instead of exploring alternative strategies and means for completing the task. While the structured, formalized techniques have advantages for certain aspects of system design, the rules they impose make them not as appropriate for use as a knowledge elicitation tool, and thus, were not used in this research.

This section has highlighted three of the most widely used techniques, the abstraction hierarchy, decision ladders and concept maps, that CSE practitioners use to represent and model expertise and knowledge. In the following section, 2.3.4, Vicente’s (1999) framework for studying work is presented. After that, more ‘opportunistic’ frameworks for conducting CSE are introduced in section 2.3.5.

### 2.3.4 A Prescriptive Approach to CSE: Cognitive Work Analysis

Building on the foundations of the abstraction hierarchy (Rasmussen 1986), Vicente developed a framework for studying socio-technical systems called Cognitive Work Analysis (CWA). Noting that the actual practice of studying work is generally chaotic and opportunistic, Vicente argues that a more formalized structure to designing a study of work is important, and outlines a five stage plan for work analysis. At the heart of Vicente’s work is collecting data and populating the Abstraction-Decomposition Space based on the foundations of Rasmussen (1986; 1994), and described above. Understanding work involves examining the adaptive nature of work performance. This examination is comprised of studies of how individuals adapt to their specific work space, and how the interdependencies of the organization are affected and adapt to changing technologies and environmental pressures (Rasmussen, 1998).

CWA is a theoretical framework for conducting work analyses based on behavior-shaping constraints. CWA uses multiple techniques for representing how humans conduct work. Cognitive work analysis involves five stages for producing models of the work domain including...
the work domain itself, control tasks, strategies, social-organizational factors, and worker competencies (Vicente, 1999). Vicente (1999) argues that in order for a work analysis framework for the design of a complex system to be effective, it must 1.) support workers in situations where they have to adapt and cope with unfamiliar, and unanticipated events, 2.) identify system functionalities that are required for accomplishing tasks when individual judgment calls are required, 3.) be based on humans capabilities, limitations, with consideration of usability issues, and 4.) empower workers to make decisions, and provide flexibility to the decision making process as workers competency and skills develop.

Work Domain Analysis (WDA) is the first stage of a comprehensive CWA approach to studying work developed by Vicente (1999). Vicente (1999), Rasmussen (1998), and Rasmussen et al. (1994) stress that WDA is the most important stage within CWA. The five stages of the formative approach are highlighted below (figure 2.8). The process begins at the top of the figure where the focus is on the ecological context of work and proceeds to the bottom where the focus is on individuals and cognitive elements of work.

Figure 2.8: Five stages of Cognitive Work Analysis (Vicente, 1999)

Vicente (1999) recommends specific methods for representing and understanding each level of work and what information the specific methods will uncover. In the figure 2.9 below, Vicente’s (1999) view of how to conduct a study of work is presented. The left column displays the five stages of CWA. The middle column presents the modeling techniques that Vicente advocates to understand each level. The right column describes the type of design situations that Vicente suggests each technique informs. For example, to understand the work domain, he recommends the abstraction hierarchy, which will help produce information about data models and databases. To study tasks, he recommends the decision ladder, which helps identify procedures and automation. For the study of socio-organizational aspects, Vicente (1999) suggests that each of the previous techniques inform that level. I have added social network analysis and organizational diagrams to this level, as they seem highly complementary. One of
the most difficult impediments to comprehending this prescriptive strategy for understanding work is that often, the specific formalized methods have not been applied to a single work domain, but instead, were applied individually to separate work domains. In the following sections, each sub stage is discussed.

![Diagram of stages and techniques for studying work](image)

Figure 2.9: The stages and techniques for studying work
Adapted from Vicente (1999) and Stanton (2004)

### 2.3.4.1 CWA Stage 1: Work Domain Analysis

The goal of the first stage of Vicente’s CWA is identify the *fundamental set of constraints* that individuals might face at several scales of analysis. This goal is achieved by conducting a WDA (Vicente, 1999). As mentioned earlier, a WDA is built on foundations of Rasmussen (1998) in that the focus is on describing the social organization and cooperative activities necessary to complete a task using the two dimensional modeling technique called the abstraction-decomposition space. The work domain represents the overall system that is being controlled. This system is independent of individuals, computing, events, tasks, goals and interfaces. WDAs attempt to show all possible situations that might arise in a given domain. The
greatest threat to operators of any complex system originates from events that designers failed to anticipate and that surprise the system operators. WDAs help designers identify, and thus plan for the occurrence of such unanticipated activities (Vicente, 1999) as well as to inform the design of databases and sensors.

2.3.4.2 CWA Stage 2: Control Task Analysis

The second stage of Vicente’s (1999) framework is the identification of control tasks and the subsequent modeling of the elicited knowledge with decision ladder representations (shown above). This stage is closely related to traditional CTA approaches. The objective of control task analysis is to obtain information about specific tasks and the required actions in a given problem domain. Control Task Analysis helps the expert elicit what needs to be done for a given problem domain (Vicente, 1999). Vicente (1999) transforms task functions into decision ladder representations that describe the situation analysis, goal evaluation, and the planning and action required for individual tasks. Decision ladders are then used to identify the procedures in a work domain, and strategies for automating such work.

2.3.4.3 CWA Stage 3: Strategies Analysis

Strategies analysis focuses on the identification of how the control tasks identified in stage two can be implemented. Information flow maps represent the modeling tool for strategies analysis. Control task analysis and strategies analysis focus on the actions within a work domain rather than the specific work domain itself. A strategies analysis represents a process description of how a task can be done. In complex systems, there is more than one way to accomplish any given task. Strategies analyses help elicit the variety of approaches that might be undertaken to accomplish a specific task, and compare and contrast them with one another. Vicente (1999) suggests that strategies analysis is important because it provides design guidelines for systems to support multiple methods for accomplishing a given task. It informs an understanding of the process of information flow within the system.

2.3.4.4 CWA Stage 4: Social Organization

The fourth step of this framework is centered on identifying how the strategies identified in section 3 can be distributed across human workers and machine automation. The objective is to determine how humans and machines communicate and cooperate, and how the social and technical factors of a socio technical system can be merged to enhance overall system performance. Vicente (1999) combines three representation techniques (functional abstraction hierarchies, decision ladders and information flow maps that are produced in the earlier stages) into large organizational diagrams that enable the analyst to characterize the social and organizational constraints for a complex system (Vicente, 1999). This stage could benefit from
social network theory to expand the models and improve the design of collaboratively aware systems that support the structure of work and the means of communication and coordination within the domain.

2.3.4.5 CWA Stage 5: Worker Competencies

The final stage of Cognitive Work Analysis addresses what Vicente (1999) argues has been the traditional core focus of research within human factors and HCI communities. The goal is to use the identified requirements of the application domain to determine the necessary *competencies* that an ideal worker should exhibit. The first step in this procedure is consolidation of the requirements into knowledge about a given individual’s level of demand within a given situation, and the identification of what requirements are needed for the worker to cope with the situation. Vicente (1999) suggests that workers competencies analysis helps in the creation of design requirements that take into consideration human and technological limitations. These design requirements lead to the development of new interfaces and training programs for the domain being studied.

The previous discussion has highlighted the structure for Vicente’s (1999) prescriptive approach for conducting Cognitive Work Analysis in five stages. Vicente (1999) also emphasizes that the methodological approach, and thus, the order and type of activities that analysts use to collect data are more often opportunistic, chaotic, nonlinear, and iterative, and that researchers need not employ all of the techniques nor follow the specific order (depending on the researcher’s specific needs and goals). This is an important issue to stress; it is not necessary to use all of the representations and models that comprise Vicente’s CWA framework for a CSE approach to studying work to be successful. A small subset can provide meaningful feedback and guidelines for the design of complex systems (Vicente, 1999). Of importance, however, is that the knowledge elicitation techniques selected allow the analyst to create conceptual models for Cognitive Task / Work Analysis. This CWA framework provides a generalized structure for CSE and (despite Vicente’s claim that it is adaptive) researchers have considered it an example of a rigid implementation strategy.

For a newcomer to CSE, the approach (with multiple stages, multiple techniques, and multiple representations) can be overwhelming. Moreover, for researchers with limited resources, the implementation of this comprehensive approach can be cost prohibitive. However, Vicente (1999) suggests that it is necessary to address each of these levels in order to develop a *comprehensive* understanding of work. To make selection of Knowledge Elicitation and
Representation techniques easier, other researchers have adopted less formalized frameworks for studying work.

2.3.5 Alternative Approaches to CSE

2.3.5.1 Opportunistic Bootstrapping (Potter et al. 2000)

Potter et al., (2000) present an ‘opportunistic’ approach to studying cognitive tasks and conducting work analysis. In their approach, the selection of techniques and representation strategies for studying work is iterative, and begins with an idea and ends with the release of the system in the real world. Potter et al. (2000) describe CTA as a process of modeling and discovery where the focus is on building models based on elicited expertise. They consider the entire process of CTA to be an iterative bootstrapping process (meaning it builds on itself) focused on understanding work and workers (Potter et al. 2000). They argue that the process of selecting and implementing multiple converging techniques needs to focus on the products to be generated rather than details in the methods (Potter et al., 2000). By focusing on the end models, they argue, researchers will be better prepared to appropriately select and employ specific knowledge elicitation techniques for a CTA.

![Figure 2.10: Simplified Rendition of Opportunistic Bootstrapping by Potter et al. (2000)]
The formative stages of system development have been simplified in the figure above. Potter et al. (2000) merge Cognitive Task or Work Analysis together into the first stage of system development. The process starts from scratch, with an idea and progresses to a second stage of storyboard and scenario-based iterative prototype design. Before a design can be implemented, Potter et al. (2000) utilize specific elicitation techniques (labeled here as the toolkit) and modeling and representation techniques (labeled as the products). Figure 2.10 is a highly simplified version of the first stage opportunistic bootstrapping presented by Potter et al. (2000). The second stage involves the iterative creation of storyboards and low fidelity prototypes. Methods such as cognitive walk through and prototype evaluation methods help inform prototype design and development. The final stage is concerned with more formal testing and eventually, the release of the system.

### 2.3.5.2 The Living Lab Framework

Another alternative approach to studying work is The Living Lab (McNeese, 2004). Years of experience with CSE work in military command and control and computer-supported design team domains (e.g., McNeese & Brown, 1986; McNeese et al. 1995; McNeese, 2002) led to the development of a CSE approach known as AKADAM (Advanced Knowledge And Design Acquisition Methodology) McNeese et al. (1990).

AKADAM was developed by Zaff et al. (1993) for studying fighter pilot expertise and involving the pilots as participatory designers of next generation targeting systems and cockpit displays. AKADAM employed three knowledge acquisition techniques, concept mapping, design storyboarding, and IDEF-0 functional decomposition. A follow up strategy for employing CSE methodologies was the COLLATA paradigm that McNeese & Rentsch (2001) utilized. COLLATA built upon AKADAM, as a structure for designing and conducting ethnography and knowledge elicitation sessions. Specifically, COLLATA was based on techniques such as collaborative team protocol analyses, group knowledge elicitation, team cognitive task analysis, and group concept mapping & storyboarding (McNeese and Rentsch, 2001). These method-
based approaches led to the development of higher level frameworks for designing CSE studies discussed below.

McNeese et al. (1999) divides cognitive systems engineering approaches into six categories, consisting of goal specification, experimental data collection, knowledge acquisition, representation, evaluation, and analyses of results. These divisions were presented as a framework for structuring system development while providing a set of conceptual, computational and mathematical representation strategies for presenting the final results of the study (McNeese et al., 1999). This framework (Figure 2.12 below) can help researchers identify appropriate strategies for conducting field studies in CSE. The representation category describes mechanisms for capturing and depicting the behaviors that are identified during knowledge acquisition. This type of approach, sometimes referred to as cognitive ergonomics, is concerned with developing knowledge about the interaction between human information processing capacities and limitations and technical information processing systems.

Figure 2.12: A Framework for Conduction Cognitive Field Studies (McNeese et al. 1999)

The framework described above developed by McNeese et al. (1999) was modified and adapted into the Living Lab approach Figure 2.13 (McNeese, 2004). The Living Lab emphasizes a focus on problems, with four major stages that help inform understanding of the problem domain: knowledge elicitation, scaled worlds, reconfigurable prototypes and ethnographic studies. Models are created from the knowledge elicitation exercises and transformed into envisioned designs for the construction of scaled world simulations that lay the foundation for the development of more in-depth, real world prototype applications that can be placed in the real world work context for ethnographic and observational studies of experts.

The envisioned design can be in the form of a scenario or script that dictates the work activities. That information can be used to assist with the construction of a scaled world
Synthetic Task Environment (STE), a simulation, or a virtual or artificial world. Because it is difficult to simulate or recreate real world activities, these activities need to be scaled down to a manageable problem context. Thus, scaled world applications run abstractions of real world scenarios based on expert studies of work. A scaled world simulation can allow researchers to collect, analyze and study information about individual and team performance in controlled laboratory settings. After testing and assessing team performance in a scaled world, new envisioned designs can be developed and integrated into reconfigurable prototype applications that are placed in real world settings, completing the living lab cycle.

Figure 2.13: The Living Lab (McNeese, 2004)

This section has discussed two iterative and opportunistic frameworks for applying Cognitive Systems Engineering to the understanding of work and construction of technologies. Regardless of whether a structured approach (i.e. Cognitive Work Analysis) or an opportunistic approach is chosen researchers should first carefully consider potential difficulties and drawbacks to a CSE approach to studying work.

2.3.6 Potential Obstacles in Cognitive Systems Engineering Approaches

Researchers employing CSE methods, prescriptive and/or opportunistic, must consider relevant obstacles. Like most engineering endeavors, implementing a complete Cognitive Work
Analysis (or even initial Cognitive Task Analyses and Work Domain Analyses) requires a considerable resource investment. Moreover, these methods have been criticized for the length of time required to complete the work and for the lack of quantitative measures of significance. Potter et al (2000) provide a recommended set of evaluation criteria for researchers implementing a Cognitive Task Analysis. They recommend that practitioners evaluate the effectiveness of a CTA procedure by rating the efficiency of the approach, the validity of the results, and the effectiveness with which the results aided design. Moreover, they emphasize the importance of ensuring tractability of results by proper documentation and tracking throughout the entire life cycle for of the system design. Finally, they emphasize the importance of whether the CTA analyses have predictive power for exploring and designing new technologies (Potter et al, 2000). Even with such criteria to use as a litmus test, there are still limitations in all CTA or CWA approaches.

Vicente identifies three primary limitations for investigators implementing the process of Cognitive Work Analysis as described in (Vicente, 1999): 1) Implementing a CWA approach takes an incredible amount of effort and investment of time and resources. To overcome this problem Vicente (1999) advocates focusing on automating the procedures for conducting the analysis or developing prototype templates for application domains that capture the constraints that are both common and unique to a given problem domain. 2) CWA is based on a formative approach, which means that design considerations proceed from a ‘clean slate’ perspective that begins with a conceptual idea and ends with release of technology. However, most system design follows an entirely evolutionary process, and thus, is rarely able to proceed from conception as a ‘clean slate’ through later implementation. 3) The last point of concern Vicente (1999) mentions is that the CWA framework advocates that the fieldwork team must develop and finish the final design and resubmit it to designers (Vicente, 1994). External constraints (e.g. deadlines, project turnover, system failures) can influence the design of complex technological systems, and maintaining a central focus and schedule for development is often a difficult task for collaborative design teams. Nevertheless, until more research proves that these obstacles are too great to be overcome, Vicente (1999) advocates the adoption of this CSE strategy.

2.3.7 Summary

In the previous sections, the overall structures for studying work were discussed. Prescribed and structured approaches such as those advocated by Vicente (1999) and Rasmussen (1986) represent one type of approach to studying work, and more opportunistic approaches like those of Zaff et al (1993) and Potter et al. (2000) are another type of implementation strategy. A third, that builds on elements of both approaches is the Living Lab approach advocated by
McNeese (2004). All of these approaches are examples of high-level methodological and conceptual frameworks for understanding an entire domain of practice or field of work. Once the structure of the approach has been chosen along with the models that will be used to represent that knowledge, specific knowledge elicitation techniques for eliciting expertise need to be chosen for studying work.

2.4 Expertise, Knowledge, and Knowledge Elicitation

The following sections discuss the nature of knowledge and expertise, and the methods that are employed for eliciting that knowledge. The selection of specific techniques depends on the theoretical approach adopted (e.g. CWA, CTA, etc), the constraints of the work domain, and the goals for the final representation of work activities.

2.4.1 Expertise

Researchers have identified and classified levels of expertise, however there is no agreement on the categorizations. Here, an introduction into expertise and a summary of the meta-categories are presented. During the Renaissance, people sought to define levels of expertise. For example, guild systems of that time characterized the levels of expertise from someone who has no experience with a domain through the master sage of a given trade (Hoffman et al, 1995). The following descriptions are from Hoffman et al. (1995) and summarize several basic categories of expertise.

Naivette – one who is totally ignorant of the domain.

Novice – literally, someone who has been brought through an initiation ceremony, - a novice who has begun introductory instruction.

Apprentice – literally, one who is learning – a student undergoing a program of instruction beyond the introductory level. Traditionally, the apprentice is immersed in the domain by living with and assisting someone at a higher level. The length of an apprenticeship depends on the domain, ranging from about one to 12 years in the craft guilds.

Journeyman – literally, a person who can perform a day’s labor unsupervised, although working under orders. An experienced and reliable worker, or one who has achieved a level of competence. It is possible to remain at this level for life.

Expert – the distinguished or brilliant journeyman, highly regarded by peers, whose judgments are uncommonly accurate and reliable, whose performance shows consummate skill and economy of effort, and who can deal effectively with rare or “tough” cases. Also an expert is one with special skills or knowledge derived from extensive experience with sub domains.
Master – traditionally, a master is any journeyman or expert who is also qualified to teach those at a lower level. Traditionally, a master is one of an elite group of experts whose judgments set the regulations, standards, or ideals. Also a master can be that expert who is regarded by the other experts as being “the” expert or the “real” expert, especially with regard to sub domain knowledge.

2.4.2 Knowledge

In each of the categories of expertise, the level is determined by the knowledge and skills of the expert. The type and depth of knowledge that can be elicited from an individual will differ depending on which of the expertise categories the individual is in (Hoffman et al., 1995). For example, if all knowledge elicitation techniques are aimed at tapping the knowledge base of experts, a definition of the knowledge base is required. Knowledge elicitors might be interested in discovering such things as experts’: schema, mental models, representations or strategies. However, the type of knowledge contained within those categories is not consistent.

The following categorization represents one way of examining the types of knowledge to elicit. If the focus of the elicitation is on ‘what’ then it is explicit or declarative knowledge. Explicit or declarative knowledge consists of factual statements, if/then rules and analytical procedures and can be derived from artifacts such as manuals, organizational charts, guidelines and standard operating procedures. If the focus is on ‘how’ then the knowledge is procedural. This type of procedural knowledge differs from that which is found in books because often experts develop their own procedural strategies and short cuts that fall outside of the information represented in manuals. If the information is based on ‘why’ then the category of knowledge is often considered tacit, or based on theory and/or intuition (it is also possible to have explicit knowledge about why, such as the answer to ‘why’ is the sky blue?, but that question essentially asks ‘what causes the sky to appear blue?’). Tacit knowledge is that which is resistant to articulation, is highly context dependent, can be related through analogy, and often involves a gut feeling or instinctual response. Another type of knowledge, partially related to procedural knowledge, is inferential and experiential knowledge. This type of knowledge is perceptual, and is centered more on motor feel and muscle memory and would be particularly relevant for activities such as flying airplanes, playing an instrument or swinging a golf club.

With so many types of knowledge, it can become difficult to focus on the type most applicable to designing technologies. For example, an interviewing technique might be useful for tapping a single type of knowledge, but observational techniques might be necessary to learn other areas of expertise. Because of this dilemma, Hoffman et al. (1995) posited the ‘Differential Access Hypothesis.’ This idea essentially argues that different knowledge elicitation techniques
are aimed at tapping different types of embedded expertise. Given this primer on knowledge and expertise, the following section highlights categories of specific techniques that are used to elicit expertise.

2.4.3 Knowledge Elicitation and Acquisition

Cognitive systems engineering research suggests that it is first necessary to obtain a detailed understanding of how experts currently work within their domain; knowledge elicitation and acquisition techniques support this goal. Intelligent system design is often hindered by the difficult task of eliciting domain specific knowledge from experts (Zaff et al, 1993). Human or user-centered knowledge acquisition follows a methodology that facilitates flexible access to information (open-ended questions and interviews), provides a medium for shared communications, and involves procedures that are compatible with the way the domain experts think about their work domain (Zaff et al., 1993).

Knowledge elicitation and acquisition techniques are applied at the ‘front end’ of the process to build expert systems via a cognitive systems engineering approach (Cooke, 1994). Specific techniques depend on the overall structure of the CSE process that the researcher chooses. Knowledge elicitation is the process of collecting relevant information from a human source (Jones et al 1996). A key distinction of knowledge elicitation is that it involves the collection of human knowledge from individuals, whereas other knowledge acquisition techniques support knowledge collection from multiple sources such as written documents, manuals, textbooks, etc (Cooke, 1994). Knowledge acquisition involves the elicitation of knowledge and also the explication and formalization of that knowledge. Cooke (1994) suggests one of the primary goals of knowledge acquisition is to externalize knowledge in a form that can be encoded and accessed via computers. While some authors equate multi-source knowledge acquisition with knowledge mining, most authors consider knowledge acquisition to be concerned with modeling and construction, with knowledge mining serving as one input to that process.

Cooke (1994) classifies knowledge elicitation techniques into three families, 1) observations and interviews, 2) process tracing, and 3) conceptual techniques. Each category contains several individual techniques. The following discussion adopts Cooke’s classification, and presents a table of techniques at the beginning of each section, and then discusses some of the most useful and popular techniques. This ordering could be implemented in a real world analysis application. The subsequent sections describe, compare, and contrast individual CSE Knowledge Elicitation (KE) techniques. Each technique is described in terms of the data collection procedures. Notes on where specific techniques could be applied within a CSE technical design framework are highlighted.
2.4.3.1 Observations, Interviews and Task Analysis

Observation and interviewing techniques (Table 2.1) are direct methods for watching experts and discussing their work in their work domain (Cooke, 1994). These families of techniques are the most frequently used for KE generally, and are useful for forming an initial conceptualization of the problem domain. There are three major sub-categories outlined below: observations, interviews, and task analysis. Overviews of the categories of techniques are presented in the following sections.

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Table 2.1: Observations Interviews and Task Analysis
(Cooke, 1994; Hoffman et al., 1995; Jones et al 1996)

Participant observation techniques are among the most powerful knowledge elicitation tools because they do not rely on verbal descriptions or expert memory and instead rely on first-hand observation. Cooke (1994) points out that observation tools are useful for identifying
problem-solving strategies, studying motor skills, automated procedures, and identifying limitations and constraints of various domain tasks, the data required for task completion, and for verification of data from interviews and/or questionnaires. Observation techniques include activity logging and written, audio and video recordings of domain practitioners at work.

Knowledge elicitors are actively involved in observation techniques, often focusing on only a small subset of the problem environment and structured and recorded along a pre-specified format. These techniques minimize interference with the participant and task achievement. Cooke (1994) distinguishes among 5 task types, to which observation techniques can be applied: familiar tasks, simulated familiar cases, tasks with available limited information, constrained processing tasks, and demanding or tough cases laden with problems. Identification of problem scenarios represents one of the most useful tools for revealing true expertise (Cooke, 1994).

Interview techniques are the most commonly used knowledge elicitation procedures available. They range from highly structured, direct questioning to indirect, unstructured formats (Cooke, 1994). Often, interviewing techniques require the expert to remember a past event, or reflect on a prior experience. Interviews can be recorded through note taking, audio, and video means, or some combination thereof. A wealth of literature on interviewing techniques is available in a range of disciplines. See Hoffman et al. (1995) and Cooke, 1994 (knowledge elicitation); Creswell (1997) (qualitative research methods), and Nielsen, 1993 (usability engineering) Kirwan and Aisnworth (1992) for detailed summaries. These interviewing techniques are well suited for use during the initial phases of knowledge elicitation in order to assess the needs of the user’s domain. They can also assist with building a rapport with the experts which can lead to strong relationships that might allow the continuation of knowledge elicitation methods. One drawback is that the transcripts from interviews are time consuming to produce, are difficult to use, and for all interview types, there is no overarching framework for presentation of interview results; however Creswell, (1997) outlines several techniques.

Interview techniques are generally aimed at obtaining information about individual case studies or goals. For example, a common technique that elicits important case scenarios is the identification of critical incidents. The Critical Incident Technique was developed in the 1940s by John Flanagan (Flanagan, 1954). It has been adapted into the Critical Decision Method by Gary Klein (Klein et al., 1989) for the study of non-routine events in Naturalistic Decision Making contexts. A specific application of its use is described in Hoffman et al. (1998). A general overview of this approach is that experts are asked to identify cases that were interesting, rare, non-routine, memorable, funny or difficult. Because hypothetical scenarios can be difficult
for interviewees to generate during interview settings, the critical incident technique allows researchers to identify, and prioritize cases of importance. A further advantage is that the technique promotes the construction of timelines relating the sequence of events.

Usability engineering experts view task analysis as a detailed study of users’ overall goals, their current method for accomplishing tasks, their information needs, and how the task is accomplished under emergency circumstances (e.g. loss of power) (Nielsen, 1993). Schneiderman (1998) argues that too often, task analyses are done informally or implicitly. The history of task analysis suggests that tasks should be broken down into both high-level tasks and command level tasks. One important product to be gleaned from task analysis is the users’ mental model of the task (Nielsen, 1993). The users’ model can assist interface developers in the creation of metaphors more closely linked to actual users. Other information such as “workarounds” to task completion can also assist in effective interface design (Nielsen, 1993). Notice here that UE experts recognize the need for conducting a task analysis and identifying users’ models of the task, but often do not provide means by which the data can be analyzed, represented, and then converted into representations of the models of work, individual workers’ mental models, or a series of design guidelines that are documented in CSE methodologies.

Task analysis techniques can involve both observations and interviews that are focused on the specific functions one must perform to complete tasks and subtasks. Task analysis in Cognitive Systems Engineering is concerned more with the representation of data and information that was garnered during knowledge elicitation sessions such as observational studies or interviewing techniques than with the collection of data (Cooke, 1994). A difference between just task analysis and cognitive task analysis is that in the latter, emphasis is placed on identifying the problem context and gaining an understanding of the cognitive demands of the task.

### 2.4.3.2 Process Tracing

Cooke (1994) presents the process tracing family as a more formalized method for knowledge elicitation than the observational and interviewing family because the techniques focus on exploring the cognitive structure of the participant’s thought process and the activities and actions underlying task performance. Process tracing techniques ask participants to complete specific tasks, and in doing so, to discuss the cognitive and procedural issues required to perform the task. The researcher often collects observational information to help provide a more in-depth understanding (meaning they collect eye movement, and other motor functions required for completing the task). A critical issue is the selection of representative task scenarios. Process tracing techniques are also considered more formal because they include both knowledge
elicitation and the analysis of the data. See Woods (1993) for a detailed discussion of process tracing methods in work contexts.

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<th>PROCESS TRACING</th>
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Table 2.2: Process Tracing Family (Cooke, 1994)

Cooke (1994) suggests that most process tracing exercises have focused on the use of verbal data to elicit knowledge. Such verbal reporting techniques require the domain expert to verbally communicate the processes required to complete the actions, procedures and knowledge that underlies a particular task. Verbal report techniques receive criticism because the task of verbally explaining actions and tasks (as with talk aloud or think aloud protocols) can interfere with the specific activity that analysts are measuring. The use of verbal reports is controversial, and moreover, results in the creation of large datasets that can be difficult to interpret (Cooke, 1994). However, when compared to interviewing and observational studies, these techniques provide systematic and rigorous approaches to understanding human thought and cognitive processes.

Non-verbal data (also collected in observational studies) are important to the process tracing family. Data collection of eye movements, keystroke logging, head tracking, and gesture interaction are examples of non-verbal reports that can be collected during process tracing knowledge elicitation studies. Any data that cannot be verbalized but is essential to the completion of the task being studied falls within this category. Mouse tracking and patterns of web browsing or file access use are among the other types of non-verbal data (Cooke, 1994). Marketing and advertising strategists increasingly log and record non-verbal reports.
Furthermore, as vision tracking software advances, the design of multimodal systems will require the use of non-verbal reports to obtain information on how users interact. The process of designing collaborative technologies might also benefit from non-verbal reports by collecting large amounts of data, and categorizing the actions into system-related interaction, collaborative interaction, and useless interaction.

Cooke (1994) characterizes protocol analysis techniques as attempts to automate the data coding process in a systematic and objective fashion. For example, the data collected from experts during a verbal reporting technique can be unordered, complex, and largely qualitative. To assist the analysts coding the data, computational software packages and methods (such as content analysis and automated protocol analysis techniques) were developed to systematically and objectively organize the qualitative data by seeking regularities and patterns (Cooke, 1994). These data collection methods have a substantial learning curve that must be overcome before they can be used effectively.

Decision analysis techniques are a continuation of verbal and non verbal protocols through quantitative means. Decision analysis uses formal statistical methods and probability theory to create quantitative information about decisions. Because these techniques focus on a single aspect of performance, they provide the analyst with extremely detailed representations of the output of the decision making process (Cooke, 1994).

2.4.3.3 Conceptual Techniques

Conceptual techniques are those that focus on capturing information about specific concepts in a given domain, and the interrelationships within and among those concepts (Cooke, 1994). Cooke (1994) states that the techniques within this family (such as concept mapping) are indirect, and require less introspection and verbalization than the previous two technique families. These techniques are best at handling multiple experts, and thus, are well suited for collaborative problem domains. These techniques are, however, restrictive in that they often do not cover the entire range of knowledge, but instead are more focused on specific concepts and their relationships (Cooke, 1994). Therefore, these techniques should always be applied in conjunction with techniques from one of the other families. Table 5.3 outlines the techniques found within this family.
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Table 2.3: Family 3 – Conceptual Techniques (For detailed descriptions see Cooke, 1994; Zaff et al., 1993; Hoffman et al, 1995; Rasmussen, 1998; Vicente, 1999; Jones et al 1996)
Concept elicitation techniques use a set of objects, elements, and parts in order to understand a domain. These techniques (such as concept mapping introduced earlier) often allow the analyst and the expert to have a shared communication medium through which to converse. A shared communication medium is one that provides the analyst and the participants with a mutually accessible record of the discussion domain (Zaff et al., 1993). In concept mapping, the analyst and expert work to develop and refine the model during the interviewing process. This approach not only provides analysts with flexible, yet structured discussions, but also allows an immediate means by which the elicited knowledge can be visualized, represented, and verified. The concept mapping technique also reduces the demands placed on the analyst to interpret the data correctly, by allowing real-time verification with direct input from the domain expert (Zaff et al., 1993).

The approaches for conducting KE via concept maps vary. In the Pilot’s Associate program, Zaff et al. (1993) conducted concept mapping exercises with pilots on large wall sized white board displays. Hoffman (personal communication, 2003) has elicited concept maps from weather forecasters in real-time using the CMapTools software on a laptop computer (though he enters a caveat that only KE experts should attempt this method as it is extremely easy to allow the computer interface to become a hindrance and obstacle to knowledge transfer).

Early discussions of the role of concept mapping in learning and education are reported in Lambiotte et al. (1989) and Novak and Gowin (1984). Concept maps were used as a knowledge elicitation technique for CSE by Zaff et al (1993). An advantage of examining the resulting concept map is that, “the map’s spatial properties allow the individual to immediately identify characteristics of the knowledge domain such as overall complexity, differential complexity of sub areas of the map, areas of symmetry and gaps in the domain expressed by breaks in symmetry, continuation, or closure,” (Lambiotte et al 1989; 359). Concept maps can also help researchers capture the temporal aspects of work processes by embedding a timeline within the relationships depicted by the concept map. Moreover, concept mapping can be used for collaborative analysis of multiple domain experts, and they can be compared with one another to ascertain differences among problem solving procedures or individual tasks (Zaff et al.,1993). Because the model or representation of the user’s problem domain is constructed during the actual data collection session, this is one technique that merges elicitation and representation into a single approach. See Zaff et al. (1993) and McNeese et al. (1995) for a detailed account of the process for implementing a concept mapping approach.
Concept mapping is a rapidly expanding method of knowledge elicitation. 2004 marked the creation of the 1st International Concept Mapping Conference. Efforts currently underway by Joseph Novak, Robert Hoffman and John Coffey are actively exploring criteria for creating ‘good’ concept maps (Hoffman, 2004 personal communication and unpublished manuscripts).

Cooke (1994) describes the category of ‘data collection methods’ as methods for collecting estimates about the degree of relatedness between domain concepts so that researchers can summarize concepts and make comparisons among multiple individuals. There are both direct and indirect techniques for collecting data. For example, in rating and ranking, experts are given pairs of concepts, and asked to assign rankings of relatedness to each pair. These data can then be compared for all interviewed domain experts to gain a combined understanding of the problem domain. An indirect technique is one that captures recordings of the expert’s physical actions during interface interaction. See Cooke (1994) for a more detailed description of this category of techniques.

Structural analysis techniques consist of descriptive, multivariate statistical techniques that reduce pair-wise estimates of items into simpler forms (Cooke, 1994). The selection of a structural analysis technique is determined by specific data representation needs and data assumptions. Structural analysis techniques allow the analyst to focus on the conceptual structure of the domain under investigation. These techniques also help researchers reduce the amount of data, teasing out the most important, salient characteristics. Cognitive Structure Analysis is one such technique that asks the expert to discriminate between forms of representation. Multidimensional scaling, factor analysis, and statistical clustering are among the techniques Cooke (1994) identifies as being important for structural analysis.

Several of the structural analysis techniques described above have been automated via computing technologies, reducing the amount of time required for knowledge elicitation. Elicitors can get feedback quickly by using such automated techniques (Cooke, 1994). These automated schemes have expanded with the development neural network applications, among others. As computerized knowledge discovery techniques develop and expand, the role of automation become increasingly important for knowledge elicitation strategies used in Cognitive Systems Engineering.

All of the techniques within the three families (observations and interviews, process tracing and conceptual) described above are at the disposal of the researcher. The selection of the types of techniques used can be influenced by the needs of the developer, the technology user, the
time constraints, as well as by the resources available and the type of expertise that needs to be elicited.

2.5 Review of GIScience Literature

To develop an understanding of the role of geospatial information in a specific application area such as emergency management, an important first step is to develop an understanding of the history of the use of geospatial information and how that history informed the design of modern technologies. The following sections provide a selected history of developments towards modern GIS, GIScience studies aimed at understanding work with GIS technologies, and finally, strategies for modeling work with GIS.

2.5.1 Selected History of GIS

Technological advances have yielded a burgeoning increase of information technologies that, when coupled with the proliferation of mobile devices, have forever changed the way individuals interact with information. Similarly, developments in geographic information science (GIScience) (e.g., Kraak and MacEachren 1999; Mark, 1999), and in computer graphics/visualization (e.g., Brown et al., 1999), suggest that maps, images, and computer graphics are becoming a common medium for communication as well as mediators of collaboration – in a range of contexts from microscale analyses of locating effluent discharges to mesoscale analyses such as hazard planning to macro scale problems like global climate change.

Geographic Information Systems (GIS) have a long history, deeply rooted in traditional geographic research endeavors. Demers (2003) argues that the methods by which the earliest explorers refined their techniques for mapping spatial distributions and geographic phenomena is the heart of how advances in mapping have been handed down and incorporated into modern GIS for over 2500 years. GIS emerged at the national scale in the 1960s in Canada (Aronoff, 1991). For detailed histories of early GIS applications in agriculture and land use, forestry and wildlife management, archaeology, geology and municipal decision making contexts, see Aronoff (1991). Demers (2003) presents a detailed account of the issues surrounding the development of the earliest GIS in Canada, and relates difficulties encountered then to modern applications in GIS. For a specific account of the pioneering developments of the Canada Geographic Information Systems (CGIS), see Tomlinson (1988).

During the 1980s, interest in GIS grew rapidly prompting industrial startup companies and the establishment of laboratories and research centers in national and international contexts. Of particular note were the first industrial developments at Environmental Systems Research Institute (ESRI) (today, the international leader in GIS technologies) discussed in Dangermond
and Smith (1988). Another important contributor to early GIS technologies was work conducted at the Harvard Laboratory for Computer Graphics and Spatial Analysis discussed in Chrisman (1988).

GIS has evolved extensively over the past 40 years, and in doing so, has been subjected to a variety of definitions and labels. For the purposes of this dissertation, the definition of GIS will be that advocated by Demers (2003) and previously introduced by Marble and Peuquet (1983). The definition breaks GIS into four subsystems that consist of 1) data input, 2) data storage and retrieval, 3) manipulation and analysis, and 4) a reporting subsystem for display of these data. This dissertation will seek to contribute to the continued evolution of GIS by improving understanding of the role of the user, the work practice, and the interfaces through which users of geospatial information interact with modern GIS.

2.5.2 Understanding and Modeling Work with GIS

The goal of understanding how geographic information systems are used within the context of the work domain is not a new idea, and was advocated by Aronoff (1991). He argued that the success or failure of GIS in any organization would be dependent on the degree to which the organization understood what a GIS was, why it was needed, and how it could be most appropriately used within that organization. Similarly, Peuquet and Bacastow (1991) advocated iterative prototyping as a strategy for incrementally implementing GIS within organizations. They argued for a five step approach (technical development, prototype development, pilot system, operational system, and evolutionary development) to ensure the effectiveness of the GIS strategy before expending the resources required for implementation. It is important to note that both strategies place the role of understanding primarily on the organization, and not solely on the designer or GIS software developer. Also, Aronoff (1991) noted that a significant challenge was to develop an understanding of not only the formal but also the informal information flows within an organization before implementing a GIS; he also recognized that injecting new technology into an organization without first understanding the organization’s work practices would disrupt the system. One thing missing from Aronoff’s (1991) argument was a methodological approach to understanding and modeling work within the particular domain. This dissertation contributes a methodological approach to user-task modeling work in GIScience.

Aronoff (1991) was not alone in advocating modeling of work. The examination of work in context with regards to GIS and geospatial information was begun in the 1970s. The early work-related research was not continued, and most of the research in GIS followed a technology centered view point (Demers, 2003). Demers (2003) argues that most modern implementation problems with today’s GIS are non technical, and instead are related to user requirements and a
mismatch between software and the needs of users (including available personnel, data needs, analysis needs, training and acceptance).

The process of GIS design and implementation is a complex task. Discussing the design of GIS, Demers (2003) breaks the process into the design of software and systems. The software side is concerned with data structures, models and programming and the systems side is concerned with interactions within and among individuals and organizations. He further breaks down GIS design into technical issues and institutional design. Tomlinson (2003) suggests that an appropriate method for understanding how GIS will be used and implemented in the workplace consists of identifying the organization’s information needs through brainstorming and then building workflow models of the complex business processes conducted by the group (such as conservation land planning, delivery of services, etc). A workflow is a plan through time to sequence a related series of work activities that operate within a larger context of the business operation (Tomlinson 2003). As an example in the context of emergency management response, a workflow would be the process by which a GIS analyst obtains data and creates a map of a flooded region. Associating that map in the larger organizational context involves examining who in the organization is going to collect, manage and distribute the data, provide technology support to create the map, and ultimately distribute the map in a given problem context. A deficiency in workflow modeling is that the process yields models that are often simplistic, and represent typical daily work situations. They do not address the intricacies of collaboration and cooperation within a work domain, or the occurrence of problems and unforeseen circumstances that arise in nearly every organization, and particularly within time-critical, emergent crisis and emergency response situations. This research attempts to build on early research on workflow modeling in GIS through the creation of complex, collaborative models of crisis management organizations, the work domain, and the context within which maps and GIS are used.

Demers (2003) discusses several models besides workflow modeling that developers can utilize to build and implement a GIS including the Waterfall model, the Spiral Model, the Decision system matrix, among others. Simplified overviews of these models are presented by Demers (2003) as heuristic examples of modeling techniques that could potentially help developers. This dissertation builds on these initial ideas and provides an alternative, detailed methodological approach to modeling map and GIS use within an organization, and a description of the specific implementation of the methods for achieving an end result model of GIS use in a domain of practice.

Specific studies of GIS users at work were initiated in the mid 1990s. Davies and Medyckyj-Scott (1994; 1995; 1996) are early examples of observational studies of GIS users.
Their workplace observation study used structured interviews, checklists and video recordings of users working with GIS in the United Kingdom. Davies and Medyckyi-Scott (1995) report that most of the problems that they observed were focused on difficulties with the GIS interface. Two related studies (Davies, 1995; Davies, 1998) found that most GIS tasks dealt with the relatively mundane procedures related to data editing and manipulation, database updates and queries, and the task of producing finished, printed maps. Davies (1995) specifically used Rasmussen’s Abstraction Hierarchy (an early attempt in GIScience that used techniques from CSE); the research classified the large majority of observed tasks as occurring at the Generalized Function level of the abstraction hierarchy (a generalized function combines one or more sub-functions to complete the task).

The previous sub-sections have covered, briefly, the history of GIS development and the development of models of GIS work in a domain of practice. The next sub-section highlights how maps and GIS are critical for decision making in a range of specific contexts, and then seeks to illustrate how such technologies are underutilized because current GIS software systems are difficult to use and are not designed to support group work. The focus of this research is on decision making activities in emergency management. Before examining how geospatial information influences emergency management, it is useful to see how GIS and geospatial information has been used in other decision making contexts, independent of kind of decision making.

2.5.3 Geospatial Information in Decision Support

Geospatial information is used in a wide array of decision making tasks, ranging from determining the best places to build new businesses, to the distribution of supplies in emergencies, through public participation planning meetings. In most cases, maps help clarify discussions and ease the decision making process by serving as a medium for communicating where one thing is in relationship to another. For example, in city planning meetings, the use of a map during discussions surrounding the spatial placement of a landfill and its affect on land value is an invaluable tool for creating a common ground through which individuals can discuss and evaluate the alternatives. The next five subsections highlight the use of geospatial information in different decision making contexts including: environmental decision-making, public planning, command and control, and emergency and crisis management.

2.5.3.1 GIS and Environmental Decision Making

Environmental management decision-making activities represent some of the earliest applications of GIS technologies in this problem context (see Aronoff, 1991 for an overview).
Early work has now expanded into a wide range of decision support applications for environmental management. An important area of research is on the integration of GIS and various decision support tools. For environmental issues specifically, Fan-tang et al (2001) merged a GIS with decision support tools to create an Environmental Decision Support System (EDSS) and illustrate its utility for trans-boundary water pollution issues, drinking water site selection, pollutant monitoring, environmental impact assessment and water quality zoning issues in the Pearl River Delta.

Fisher et al (2001) advocate the use of multimedia and interactive graphics for merging and integrating maps, tables and textual displays, the products of environmental surveys. Bojorquez-Tapia (2002) worked to integrate fuzzy logic and GIS in order to better represent environmental impact assessment results. Recognizing the proliferation of complex tools that merge environmental process models and GIS, Renschler (2003) developed a framework for designing geospatial interfaces so that individuals without GIS expertise could participate in soil and water conservation planning meetings. Hannam and Osbourne (2003) describe the types of support systems and implementation strategies that exist for merging GIS tools for coastal zone management. One approach to improving the utility of GIS for decision making activities is to incorporate multi-criteria evaluation tools with GIS (see Chen et al (2003)). The integration of GIS in environmental decision making contexts often have direct ties to issues in public planning, discussed next.

### 2.5.3.2 GIS and Public Planning

An element in maximizing the returns of GIS tools in planning is through ensuring that the data are organized, made interoperable, and accessible by multiple collaborative organizations. Kinzy (1998) discusses the development of such enterprise GIS to improve the planning process. Wegener (1998) describes the role of GIS in a range of planning contexts including facilities planning, sales analysis and marketing.

An increasingly important aspect of public planning, with relevance to this dissertation, is in vulnerability and hazard analysis. Local communities have been charged with the task of instituting preparedness, response and mitigative efforts with relatively low budgets. GIS has helped local cities and counties achieve these goals. Increasingly, GIS is being actively included into public communities and local officials are working to get the information into the hands of the decision makers as well as the general public.
A key element of emergency management is community preparedness. Risk and vulnerability analyses are used by emergency managers and city planners to help prepare communities to cope with disasters. For specific treatments related to emergency response and facilities management see Elliott (1995); to decision-making response to floods see Zerger (2002) and for risk planning, management and decision making see Contini et al (2000). Directly related to issues of risk assessment are efforts to develop a GIS based SDSS (Spatial Decision Support System) for the long-term management of radioactively contaminated land resources (Salt and Culligan 2001).

Efforts to enhance public participation and interaction with geospatial information and spatial decision support systems have been improved by the development of Public Participation GIS (PPGIS); PPGIS are tools that support effective dissemination (often through the internet) of geographic information resources. An environmental planning example of PPGIS was developed by Kingston et al (2000). Several notable research efforts in PPGIS are currently underway. For detailed examples see Nyerges et al (1997); Jankowski and Stasik (1997); Jiang and Chen, (2002), Harrison and Haklay (2002).

The work reported above has improved the usefulness of geospatial information in decision making contexts. Lessons learned in environmental assessments of risk and vulnerability have specific implications for the improving the mitigation and preparedness phases of emergency management. The following section discusses research in a similar context, strategic decision-making, but more focused on command and control applications than on public planning or risk management.

2.5.3.3 GIS and Command and Control applications

One of the hallmarks of GIS is that they have the potential to assist decision makers by providing up to date, relevant and timely information. An element of strategic decision-making in command and control situations requires GIS analysts to predict and forecast the types of data that are required, and how those data would be used in a range of military command and control contexts. Data forecasting could be improved by further development of multimodal GIS technologies. Specifically, the improved access to geospatial information could allow the decision makers to explore situations in context, and forecast data needs, shifting the process of data needs forecasting away from the GIS analysts alone.

Research and development of advanced, command and control systems have directed some attention on supporting multimodal interaction with geospatial information on large screen
displays. For example, a group of researchers at the Air Force Research Laboratory in Rome, New York have developed an Interactive DataWall; it is a multimodal system that allows the display and manipulation of real-time multimedia data on large screen displays in a Command and Control environment (Jedrysik et al., 2000). The researchers point out that the normal mode of mission planning is accomplished by using acetate overlays and Plexiglas boards with grease pencils. Their multimodal approach supported camera tracking of laser pointers (to control the cursor) and independent voice recognition (to support information requests such as ‘minimize window’) (Jedrysik et al., 2000). This system was tested by the Army’s 10th Mountain Division at Fort Drum, New York, and received a highly positive response (Jedrysik et al., 2000). The greatest limitation of the Interactive DataWall is that it cannot support simultaneous users. Multiple users can interact with the technology, however only one user can complete system events and actions at a time. The researchers are beginning to explore other methods for supporting multiple pointer tracking as well as multiple speaker recognition (Jedrysik et al., 2000).

Another research endeavor on multimodal interaction with maps and large screen displays for command and control has been undertaken by researchers at the Oregon Graduate Institute (Cohen et al., 1999; McGee et al., 2000). The researchers conducted observational studies with Marine Corps commanders participating in field exercises. The researchers videotaped and transcribed typical gesture and verbal interaction with maps laid on tabletops or hung on the wall. The information was then used to identify the typical mode of interaction with 2D static maps, so that it can be transferred to their pen-based interface (McGee et al., 2001).

2.5.3.4 GIS and Emergency & Crisis Management Decision Making

Emergencies happen. Hurricanes, earthquakes and floods have consistently ranked among the worst natural disasters in terms of lives lost and damage induced. However, emergency situations arise from a wide range of circumstances including natural disasters such as tornados, wildfires, landslides, thunderstorms, blizzards, and volcanoes to human caused disasters such as mine subsidence, toxic spills, nuclear meltdowns, and even terrorism. All emergencies require managers to take immediate steps to aid response and recovery, but also require preventative measures such as planning and preparedness as well as sustained efforts to reduce long-term risk to hazards, or mitigation. FEMA, the Federal Emergency Management act was passed to provide national planning and response to emergency situations. FEMA’s goal is stated below.

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“To reduce loss of life and property and protect our nation’s critical infrastructure from all types of hazards through a comprehensive, risk-based, emergency management program of mitigation, preparedness, response and recovery,” (FEMA, 2001).

The creation of FEMA has been followed by the creation of similar state, county, and city level agencies aimed at handling all types of disaster situations. In those agencies, GIS are becoming an increasingly important tool for decision making activities in emergency management. However, traditional means for displaying maps such as in figure 2.14, (a scene in the Florida State Emergency Operations Center on September 15, 1999, during Hurricane Floyd) leave room for improvement. Notice that several emergency response personnel are crowded around a single computer display; efforts to improve collaborative access to geospatial information in emergencies has the potential to improve decision making and response efforts.

In Florida, a relatively new Emergency Operations Center contains large screen displays to help support emergency management briefings and training. The center uses five overhead projectors to display 10-foot tall status reports, weather radars, satellite images, and displays from their GIS systems that are used to track severe storms and hurricanes (http://www.dca.state.fl.us/eoc/seocdata.htm). The South Carolina Emergency Management Division (EMD) also constructed an EOC based on the floor plans of the Florida EOC. Such operations centers are being built nationwide, and all could potentially benefit from a collaborative, multimodal, interactive system.

2.5.4 Problems with GIS

In each of the above decision making contexts, efforts towards improving access to the geospatial information were highlighted. However, access to geospatial information in time critical contexts such as emergency management is hindered because current GIS remain difficult to use and the technologies do not support group work effectively. A scenario that highlights some of the salient issues in GIS use during emergencies is described below.
An illustrative scenario:

The director of the Emergency Management Division of a State Emergency Operations Center has to brief the Governor on their sheltering contingency plans in the event of a hurricane landfall in their region. All the director needs is a map of the shelters along the coastline for his or her state. To accomplish this task, the director needs to sit in front of any number of ESRI’s latest product line applications (ArcView, ArcEditor, or ArcInfo). After navigating the operating system to the folder containing the GIS products, the director would have to choose between ArcToolbox, ArcMap and ArcCatalog. The director had a training course in GIS, and learned how to click the menu items, to load data into the program, and to display and print out the map. The problem is, the director learned how to do this in Arc3.1, and the division has migrated to the 8.X series. Not only does the director have no idea about the difference between ArcToolbox, ArcMap and ArcCatalog, but he also knows nothing about ArcSDE, geodatabases, ArcObjects or the host of technologies now at his fingertips with the latest released version. This lack of knowledge is not a fault of the director, but more important items often fill in his or her day to day activities. All the decision maker wants is a map that will show him where something is relation to something else.

Enter Hurricane Helga. The needs of the emergency manager for spatially referenced information increases significantly, but more importantly, the time frame in which to work has been compressed, and the last thing that the director has time for is to sit down in front of a computer and launch a GIS program to get the necessary information. Currently, this role is filled by trained GIS technicians who perform not only the basic duties of cartography and spatial referencing for the decision makers, but also keep the software running, build the databases, and obtain the data that decision makers request during emergencies.

Building on the scenario described above, the next sections seek to demonstrate that current GIS do not support human work effectively, in part, because the interfaces to GIS technologies restrict human-computer interaction to individual users interacting with a mouse and keyboard. Furthermore, a case is made for an expanded research program that seeks to explore multiple modalities of geospatial data interaction including, but not limited to the following two examples, a gesture speech enabled GIS (Figure 2.15) and pen and tablet based GIS interfaces (Figure 2.16).
Figure 2.15 Envisioned Example of a Gesture Speech Enable Interface to a GIS

Figure 2.16: Working prototype voice and sketch based interface to a GIS
One effort for improving geospatial information access is the NSF-supported Information Technology Research project, DAVE_G, a three-year project aimed at the development of a prototype multimodal system that supports decision-making tasks by experts and the general public. The goals of the project are: the development of principles for the implementation and assessment of natural, multimodal, multi-user dialogue-enabled interfaces to geographic information systems (GIS) that make use of large-screen displays and virtual environment technology. Specific sub-goals concern the use of computer vision and speech processing as a means of interpreting and integrating information and also how human-computer dialogue with a GIS influences collaboration (National Science Foundation Grant No. BCS-0113030, http://www.geovista.psu.edu/grants/nsf-itr/index.html).

The above sections have contended that computing has struggled to meet the challenge of designing computers to be not only user-friendly, but also easy to use. This deficit has placed technology only within reach of those who can afford the technology itself and the time, effort, and training needed to learn how to use it. Moreover, this paradigm of computer design has created a situation where the interfaces have hindered the decision makers access to critical emergency support information. A shift in the way in which interfaces are designed from a techno-centric focus to a human, work, and problem centered focus has the potential to place technology in reach of a larger population of users.

While more natural interfaces for GIS have been investigated for more than a decade, relatively little progress has been made in this field. Frank and Mark (1991) suggest that integrated multimodal interfaces with maps would become the standard method of interaction with GIS technology. However, to date, their prediction has not proven true. Improvements to GIS interfaces are hindered by the mismatch between what users need to do and how the interface allows the user to complete the task. Current GIS, and most computers for that manner, require users to enter commands via mouse and keyboard events. Multimodal systems represent a shift away from the standard windows-icons-menus-pointers (WIMP) mode of human computer interaction. Multimodal systems are intended to provide users with better, more robust control over information technology, such as dynamic maps (Oviatt, 1999a; 1999b).

The target system for this research, DAVE_G (Dialog Assisted Virtual Environment for Geoinformation), is based upon the earlier iMAP system (Kettebekov and Sharma, 2001). iMAP is an interactive multimodal large screen display for speech-gesture interaction with a simple map. It is based on the put-that-there paradigm (Bolt, 1980). It uses computer vision techniques to track and recognize free hand gestures of a single user, translates those gestures into cursor control, and integrates the gestures with verbal commands to initiate system commands.
(Kettebekov and Sharma, 2001). iMap was followed by XISM (Sharma et al. 2003), a prototype environment that allowed the operator to acknowledge emergencies (such as a fire) and to deploy the necessary emergency response vehicle (a fire truck). In XISM, multiple users were not supported (See Rauchert et al, 2002 for an example of a collaborative prototype). iMap and XISM use computer vision tracking to capture gestures.

To be successful, the gesture capture system must be able to distinguish between gestures intended to control the system and actions that are merely a portion of the collaborative discussion process. For the system to distinguish between the essential and non-essential gestures and verbal interactions, the iMAP developers require videotape and storyboard depictions of the gestures and speech inputs that users would typically employ. Sharma et al. (2003) outline methods for improving design, evaluating metrics, and other approaches to improving the development process. This research seeks to help the process of design by developing designs that characterize realistic interaction with multimodal, gesture-speech interfaces.

The development of natural, transparent user interfaces that utilize voice, hands, and body movements to provide input and commands to computers represents a rapidly expanding area of research (Oviatt and Cohen, 2000). The first proof of concept study in 1980, used verbal speech commands combined with manual pointing for object manipulation (Bolt, 1980). The “Put-That-There” system laid the foundation for state of the art research on multimodal systems being conducted today (e.g. Cohen et al., 1999; Oviatt and Cohen, 1999, McGee et al., 2000; McGee and Cohen, 2001; Jedrysik et al., 2000; Sharma et al, 1999; 2000; Nigay and Coutaz, 1995). The research that led to the development of today’s multimodal interfaces stem from work with single mode input systems. In order to continue the progress on multimodal research, Oviatt and Cohen (2000) argue that there is a need for broad-based, multidisciplinary research and design efforts. The DAVE_G project meets this goal through an interdisciplinary approach to designing multimodal technologies.

Sketch based interfaces (Egenhofer, 1997; Oviatt, 1997), for example, represent an attempt at moving toward incorporating natural gestures in human computer interaction. Within GIS specifically, Egenhofer (1997) introduced the idea of formulating spatial queries by drawing with a pen on a touch-sensitive computer screen. He and his colleagues, (Schlaisich and Egenhofer 2001; Blaser and Egenhofer 2000) developed prototypes that allow users to utilize a sketchpad metaphor by drawing graphical sketches to perform basic GIS operations and spatial queries. They argue that by simplifying the interaction between the human and the computer, the spatial query process is improved because query formulation becomes the user’s primary focus.
Blaser and Egenhofer (2000) suggest that their system is multimodal in that it can parse both text and sketch based queries.

Pen-based unimodal and multimodal systems represent an attempt at creating transparent human computer interfaces. One study compared unimodal input with multimodal input (Oviatt et al., 1997). Oviatt differentiated the types of responses derived from subjects conducting a spatial task. For example, when the subjects were only able to indicate system commands via voice, a typical command would be: "Add a boat dock on the west end of Reward Lake." However, when given the same task in a multimodal system, the verbal component of the request was simplified substantially. The user drew a line on the input pad and stated "Add dock here."

The differences between pen based and gesture speech interaction highlight the degree to which the combination of multiple modalities in HCI alters the task process. These differences highlight the need for a detailed task analysis. In the above example, for instance, 11 words were required for single mode input, whereas only 3 were required in the multimodal system. Thus, multimodal interaction has the potential to significantly improve execution performance – an essential element in time critical decision-making.

Proponents of multimodal interaction, including the pen based approach, demonstrate that voice and gesture based interaction with 2D maps provides speed, robustness, and user preference advantages over traditional graphical user interfaces or unimodal speech only interfaces (Cohen et al., 1999). Oviatt and Cohen (2000) suggest that multimodal systems will supplement standard GUIs in today’s computer applications and predict that they will eventually replace such interfaces. Their argument is based on research with multimodal systems that showed a 10% increase in the time it took to complete spatial tasks as well as a 90-100% user preference rate for multimodal systems for spatial tasks (Oviatt, 1997).

While multimodal interaction via pen and sketch based interfaces (for example McGee et al, 2000; McGee et al, 2001) have led to the development of more natural interfaces to geospatial information, support for a more natural modality such as free hand gesture interaction, remains limited. Untethered, gestural interaction has the potential to redefine human computer interaction. A system based on free-hand gestures would liberate decision makers from interface concerns, allowing them to focus their attention on the problem context. Many decision making contexts also require multiple individuals interacting collaboratively to reach a consensus, yet few systems have been able to support multi-person collaborative work. Most of the initial work on developing a basis for gesture and voice interaction was limited by the technology available, and was completed as a conceptual outline (Egenhofer, 1997).
Today, technological advances have created a situation in which GIS technology, and multimodal interaction technology can be merged together into a rich, natural interface for human computer interaction. Development of these technologies requires an interdisciplinary effort to meet the technical and theoretical challenges of multimodal design. Cognitive Systems Engineering efforts are an appropriate methodological approach for addressing the design of multimodal interfaces to geospatial information. Moreover, the domain of emergency management is an appropriate context for situating work with geospatial information through multimodal interfaces. The remainder of the dissertation is focused on understanding work and with geospatial information through the application of a CSE methodology and the development of models and scenarios that inform the design of a gesture speech interface to a GIS. This chapter has discussed the relevant methodological and technical literature in CSE and GIScience. Chapter III presents the methodological approach for this dissertation.
CHAPTER III: Approach & Methods

“Science is nothing but trained and organized common sense, differing from the latter only as a veteran may differ from a raw recruit: and its methods differ from those of common sense only as far as the guardsman’s cut and thrust differ from the manner in which a savage wields his club.”

--Thomas H. Huxley--

By three methods may we learn wisdom: First, by reflection, which is noblest; second, by imitation, which is easiest; and third by experience, which is bitterest.

--Confucius--
3.1 Designing the Cognitive Task Analysis

This research is aimed at developing an understanding of work in emergency management and transforming that knowledge into designs for advanced geospatial information technologies. A central component in achieving this research goal is concerned with developing and implementing a Cognitive Task Analysis for studying emergency management. As such, this approach builds on the theoretical foundations discussed in Chapter II.

Like most CTA studies, this research pulls together a suite of methods for eliciting knowledge in the field, while maintaining a problem centered focus. This approach to CTA is similar to the opportunistic bootstrapping approach to Cognitive Task Analysis advocated by Potter et al (2000) and also draws upon the comprehensive approach to Cognitive Work Analysis (e.g. understanding the work domain, the individual task, and the social and organizational constraints, etc.) advocated by Vicente (1999). While incorporating elements advocated in the above frameworks, this work is a problem centered approach organized to be a key part of a Living Lab approach (McNeese (2004)), with results feeding into both design of scaled world simulations and reconfigurable prototypes. The approach has two goals: 1) to provide sufficient depth of understanding to support the multimodal interface design to inform development of the DAVE_G prototype and 2) to provide a basis for subsequent study that is linked through the framework of the living lab approach.

The research reported in this dissertation has the potential to scale in two directions. At one level, it is a first step in a larger effort to develop an understanding of the use of geospatial information and technology in emergency management. The larger effort would work on all dimensions of hazards and emergencies (preparedness, response, recovery and mitigation) as well as all scales (municipal, county, state, federal) and all types of emergencies (earthquake, flood, terrorism, etc). At a second level, this research traverses the knowledge elicitation, modeling, and envisioned design aspects of the Living Lab framework. To fully traverse the Living Lab, scaled world simulation environments would help inform the development of working prototypes, deployed into field offices and emergency management centers so that work with the prototype applications can be observed in context.

3.2 Selecting and Merging Techniques: An Ideal Model

As demonstrated in Chapter II, several methodological approaches and specific techniques can be integrated into studies of work (i.e. the five step approach outlined by Vicente (1999)). Those five steps represent a useful starting point for designing a comprehensive work analysis, and can help to integrate multiple methodological frameworks, conceptual issues, and
issues in expertise and knowledge elicitation techniques into a simplified approach that is easier for novices in the field of CSE to employ.

The following discussion relates some of the issues that researchers should consider when beginning a comprehensive study of a domain of practice. The bold terms coincide with the five levels of Vicente’s structured approach to studying work (Vicente, 1999), but the specific techniques and models they produce are more closely related to the opportunistic approaches advocated by Potter et al. (2000) and McNeese (2004). I view the formalized approach and the opportunistic application of techniques as complementary. This process of understanding a work domain would take years to complete, and probably involve multiple researchers conducting single and multiple field work activities aimed at developing a complete understanding of work.

The first step in developing a comprehensive CSE approach could involve the use of questionnaires and unstructured interviewing techniques to build a rapport with the domain experts, while at the same time gaining an initial understanding of the problem domain. At this stage, researchers can begin to develop functional abstraction hierarchies of work based on collected documents and information. The abstraction hierarchy can assist with the construction of a foundation of the basic functional tasks and the workers who complete those tasks in the dynamic socio-technical system. As the understanding of the domain progresses, the focus would shift to identification of specific tasks as they pertain to the overall goals of the work analysis. Knowledge Elicitation techniques including semi-structured interviews, video taped participant observation, and critical incident analyses could be conducted with domain experts and represented in decision ladders for each participant in order to uncover their decision making tasks and the strategies that are required to complete that work. Other strategies that workers employ for solving complex problems can be obtained through critical incident analyses, the Critical Decision Method, concept mapping, and scenario building exercises and represented as individual concept maps and design storyboards. To obtain knowledge about the social organization of the work domain, the decision ladders and concept maps could be merged into dynamic, group based decision ladders and concept maps, depicting the interaction among local and distributed team members. Here, social network diagrams and organizational charts have the potential to further the development of understanding of the work domain. Later, group interviewing techniques could be used to verify and refine the models produced of the socio organizational context of the work domain. Finally, worker competencies can be obtained by using a set of questionnaires that included design storyboards of the refined, envisioned design of the system with representations of the models, processes and social dynamics that the experts would refine, and finally verify a final time. These elicitation strategies should focus on
identifying the interplay of tacit, procedural, and inferential knowledge that individuals employ within the domain of study. The results of the field studies can be merged into system design recommendations for envisioned systems, and can also help inform and design new research efforts and new conceptual ideas for technology development.

Obviously, the complete process of studying work is extensive. For young researchers or seasoned veterans, embarking on such a task would involve a significant investment in resources and time. While a newly hired assistant professor might want to consider such an approach to establish a research program, other researchers may only be concerned with learning enough about a domain to build better technologies or ask more applicable research questions. Similarly, researchers may want to choose only a single CSE strategy to develop a more informed understanding of selected aspects within a domain of practice. Simplified approaches to studying work as well as streamlined methods for conducting CTAs represent an ongoing challenge in CSE.

3.3 The Approach

Emergency management involves a complex system of interconnected agencies, guidelines, rules and formalized structures. During an emergency, the established structures and guidelines have the potential to break down, requiring individuals to make life and death decisions with only the information immediately available at their fingertips. The measure of the resilience of the system is the degree to which that system can withstand such events, without failing – i.e. bend but not break – and can restore order to the situation that is moving towards chaos. In such situations, geospatial information is often critical to making key decisions, although the type, the scale and the exact nature of the geospatial information required is generally uncertain (hidden and constrained) and highly situation-specific.

The fieldwork for a Cognitive Task Analysis can be entirely observational or more participatory and structured in nature, and there are advantages and disadvantages to each approach debated frequently in the literature (see Gordan & Gill, 1997). The key point is that there is no single, best method for conducting studies of work and expertise. Individual project needs, monetary constraints, and the domain of study will all dictate the exact procedures that can be included.

There are several salient issues for a newcomer to consider when applying CSE methods of knowledge elicitation, modeling and design. Because CSE is an emerging field, careful consideration of the framework that situates the work as well as the selection of specific approaches is critical. An impediment to the selection of appropriate frameworks and techniques is the diversity of approaches that exist within this emerging discipline. For a newcomer, a more
prescriptive approach as advocated by Vicente (1999) might be more appropriate in that the structure provides enough detail to learn the methods. Equally so, a more opportunistic approach can allow the researcher to learn about the domain and techniques, and later to make better choices about the appropriate approach for further research studies. Either choice (prescriptive or opportunistic) requires a consideration of appropriate approaches and techniques based on: the project goals, the availability of experts, the work domain being studied, the complexity of the domain and the resources available to the project. Given that conducting a CSE based elicitation and modeling strategy involves such a heavy commitment of resources and time, a significant effort should be invested at the initial planning stage to ensure that the process yields effective, tractable results that contribute significant information to the overall research goals of the project. These considerations were weighed and considered prior to developing the CSE approach for this dissertation research.

The stages of this dissertation research focus on the ethnographic and knowledge elicitation components, and the results have been used to inform the design of prototypes and scaled worlds within the Living Lab (Figure 2.13). Ethnographic study and knowledge elicitation techniques are used to produce models of the work domain; those models inform the design of scenarios and envisioned designs of scaled world simulations and prototype systems. The research also contributes to the development of scaled world simulation systems of emergency management such as NeoCities (Jones et al. 2004). Software developers on the DAVE_G project used the envisioned designs to create multiple, reconfigurable instances of the DAVE_G prototype. The DAVE_G prototypes allow single and multiple users to communicate with the system via scenarios in a laboratory setting. When the reconfigurable prototypes (such as DAVE_G) have been tested in real world settings, the cycle of the living lab will be completed and begin again with new information determining new goals and technological designs based on lessons learned from the first traverse.

To accomplish the ethnographic and knowledge elicitation components, a three stage plan was developed for eliciting expert knowledge about emergency and crisis management. An overview of each stage is presented below, and the next three chapters provide details about the execution of and results from each stage. The overarching goal of this three stage process was to capture and model explicit, tacit and inferential knowledge and to mould that knowledge into design blueprints, storyboards, and scenario scripts that can be used to guide the development of new technologies for emergency management with specific application to the development of DAVE_G prototypes. A more general goal of the field work was to determine the most common
uses of GIS for emergency planning and decision-making and build that information into realistic scenarios of work with geospatial information.

To guide the construction of new technologies, results from each stage of the process were incorporated into early prototype design. For example, the first prototype of the DAVE_G system was built based on the findings of Stage I (Rauchert et al, 2002). Expert validation led to the refinement of the initial DAVE_G instantiation into a second prototype system designed to support the activities in an EOC during evacuation preparations.

As detailed in the initial chapter, one goal of this research is to illustrate the applicability of a range of CTA methods to study of geospatial information and technology use. The goal is not to prescribe a new, ‘best’ method for conducting CTA, but to instead, emphasize the core elements used for this procedure, and discuss their applicability to designing advanced computing systems.

The CTA procedure included offsite work and onsite work (Stage I and II respectively) followed by convergent domain modeling accomplished through collaborative expert verification of collected data and design of envisioned prototypes based on the acquired knowledge (Stage III). A critical, but often neglected component of studies of expertise is the development of a significant, baseline level of knowledge of the domain being studied. Methods to build such expertise include informal interviews, formal telephone interviews, questionnaires, text and document analysis, training courses, and other ‘bootstrapping’ activities. This component of the research is critical to maintain expert participation. If researchers enter the fieldwork with a limited knowledge of the field, they risk alienating the experts (e.g. by asking questions that could have been answered through a diligent study of the domain of practice). The goal of offsite work was to construct my own base-level understanding of the domain of practice (e.g. emergency management in general, hurricanes specifically) prior to onsite visits with expert participants. Stage II focused on knowledge elicitation at emergency operations centers and Stage III was focused on issues related to modeling the domain of study.

3.3.1 STAGE I: Offsite Preliminary Cognitive Task Analysis

To better understand how geospatial information is used in emergency management, preliminary data collection for this Cognitive Task Analysis focused on a series of document review and phone interviews. The initial information was used to initiate a more formalized two stage approach to understanding work in the domain. The first stage involved unstructured phone interviews and emailed questionnaires with experts. The objective was to identify a set of focused target areas within the domain of emergency management where the use of geospatial information was both critical and influential in the experts’ decision making activities. The
second offsite data collection efforts are what I refer to as opportunistic bootstrapping (different from Potter et al.’s characterization in Chapter II). Here, opportunistic bootstrapping includes the application of any data collection or knowledge elicitation method (document or policy analysis, social network analysis, training courses, etc.) employed by the researcher prior to conducting field work with experts.

This initial offsite CTA led to the selection of hurricane preparation, response and recovery as the focus of Stages II and III. The range of potential disasters associated with an approaching hurricane provided a diverse platform of study. Hurricanes are an example of a relatively slowly developing disaster. This choice allowed the study of several stages in emergency management that included pre-impact planning and preparations as well as the response and recovery stages of emergency management. Other elements of the initial task analysis included the identification of GIS operations necessary for emergency response as well as the selection of the onsite visit locations of Stage II.

3.3.2 STAGE II: Onsite Cognitive Task Analysis

As discussed above, a Cognitive Task Analysis (CTA) is largely concerned with collecting a wide range of the information that influences cognition and decision making of experts within their work domain. Onsite visits to four different Emergency Operations Centers were scheduled and conducted. The onsite visits included the following knowledge elicitation activities: artifact collection, mission scenario creation & refinement, critical incident probes, procedural concept mapping, and exit questionnaires. Applying the Living Lab, the goal of this multifaceted procedure was to collect information that could be transformed into models (concept maps, abstraction hierarchies, decision diagrams, etc) of the domain of practice as well as compiled into realistic emergency management scenarios to help design DAVE_G. It is important to note that the techniques were selected to maximize the range of expert knowledge captured. This range extends from the strictly explicit or factual knowledge that could be collected through artifacts, manuals, organizational charts and procedures, to tacit or intuitive knowledge that is contained only within the individual emergency responders, to inferential and experiential knowledge that is imbedded within the collaborative system of emergency response among all participants.

A principal focus of the activities selected for the onsite work was on generalized information gathering. Essentially, field researchers attempt to collect as much information regarding procedures, organizational guidelines, and related documentation as can be found. This procedure is often serendipitous. For the purposes of this study, efforts focused on obtaining
response plans for federal, state and local emergency management centers, as well as any software, GIS data, and related maps used for emergency response.

3.3.3 STAGE III: Modeling the Domain

Stage III focused on validation and modeling the work domain. The knowledge and artifacts elicited and collected were processed and modeled into the final results that serve as driving forces during emergency management activities while also serving as blueprints for building and designing the scaled worlds and prototype systems. In this stage, the key elements were expert validation and participatory design. Experts had to be willing to continue to participate after the onsite visits were finished, so that they could validate that the information was collected and represented accurately and could provide direction for necessary revisions. This validation was used for procedural concept maps and the resulting scenarios.

3.4 Conclusion

This chapter has presented a simplified structure for conducting a Cognitive Task Analysis in the tradition of the Living Lab framework. Chapter IV discusses STAGE I: Offsite CTA. Chapter V covers STAGE II: Onsite CTA, which details knowledge elicitation exercises conducted over a month-long period with experts in South Carolina and Florida. Chapter VI discusses the data processing, validation and design phases of STAGE III: Modeling the Domain.
Chapter IV:
STAGE I: Offsite Cognitive Task Analysis

“Study the past if you would define the future.”

--Confucius--
4.1 Introduction

This chapter describes the methods of Stage I, as defined in Chapter 3. Multiple converging techniques and methodologies were employed to elicit knowledge applicable to the work domain. Stage I consisted of offsite data collection activities about the structure, type, occurrence and hazards associated with crisis situations coupled with the organizations, teams, structure and goals of emergency and crisis management. The goal was to obtain preliminary information about what types of maps and geospatial information are used in emergencies.

Bootstrapping is a critical component of an in-depth knowledge elicitation project. Hoffman et al (1995) discusses bootstrapping as a method in which the knowledge engineer or researcher builds their own conceptual model of the domain prior to commencing with knowledge elicitation exercises. Potter et al. (2000) advocate its use for conducting a Cognitive Task / Work Analysis, and consider the entire process of studying work as ‘opportunistic bootstrapping.’ As noted in Chapter III, bootstrapping methods can include documentation analysis, literature reviews, unstructured interviews, training courses, and document collection (e.g. rules of engagement, policy, standard operating procedures). These methods, according to Hay (2000) are considered crucial to triangulating evidence collection and instilling rigor in the study.

This chapter highlights the bootstrapping methods and results from an anticipatory, proactive data collection strategy in the diverse and highly complex field of emergency management. Field researchers can find the answers to simple questions in their research area by developing a degree of baseline domain knowledge prior to interacting directly with experts. In the present research, a literature review of emergency management activities in GIS and hurricane response, plus offsite interviews and questionnaires conducted with experts constituted the first stage of a CTA applied to geospatial information technologies in emergency management.

The process was initiated with preliminary data collection activities conducted via phone conversations and literature review. These activities preceded the more formal presentation of the steps of bootstrapping outlined here. The first portion focused on initial interviews and a preliminary task analysis questionnaire. This step was conducted to focus the research down from a world view of all disasters, spatial scales, and emergency response activities to a smaller subset that would comprise the problem-centric Cognitive Task Analysis. The second portion of this chapter details the components of the collective process of preliminary data collection (subsections include literature reviews and participation in emergency management training courses). The third section discusses the effects of the findings from the offsite work on the
selection of locations for site visits, the structure of the onsite work, and the recommendations for changes to the offsite work for future studies.

4.2 Part 1: Preliminary Task Analysis

While the overarching goal of this research is to begin to build an understanding of the use of geospatial technologies and information in emergency management, a subgoal is to provide support and information to a team of system developers building DAVE_G. Initially, project and technological priorities exhibited influence on the timing and methods that were adopted. A drawback often cited in conducting expertise studies prior to designing technology is that it is resource intensive and time consuming, and thus, difficult to iteratively produce results useful for advancing technology development. Efforts were made to integrate information collected into the prototype systems at all stages of the process. So, in meeting the project’s initial technical goals, it was necessary to identify a baseline level of geospatial information use in emergency management so that prototype development could proceed. Throughout the process and before attempting to develop the interface, tradeoffs were made between obtaining usable information quickly and developing a rich understanding of the ways in which emergency managers currently use GIS systems. The first step in this process was a simple, goal based task analysis conducted via email. A questionnaire was developed to provide information about GIS use in emergency management tasks.

The overarching goal for doing a preliminary task analysis was to prioritize the types of disasters and hazards requiring the use of maps and/or GIS. The questionnaire based approach to task analysis is a common approach utilized in CSE, HCI and UE efforts. As a component of the Living Lab framework, the questionnaire in this research focuses on problem-context, and not just users and technology. A secondary goal was to characterize the nature of GIS use in the context of work in crisis management. Effort was placed on the identification of GIS tasks (such as map creation, data overlays, etc) and the necessary data required for completion of those tasks. To understand the role of GIS, specific information was collected related to GIS functions required to support activities such as firefighting, mass care, search and rescue within the context of emergency planning, preparedness, response, recovery and mitigation. A further aim in conducting this initial analysis was to provide insight into the emergency management process to create and finalize the structure for the onsite Problem Centered Cognitive Task Analysis.
4.2.1 Preliminary Investigations of Hazards in Pennsylvania

As a first step, an examination of the disasters common to Pennsylvania was conducted. After identifying the types of disasters common in Pennsylvania via internet searches, preliminary telephone interviews were conducted with experts to identify the range of disaster situations that required the use of maps and geospatial information technologies. The search began with contacts in the Pennsylvania Emergency Management Association (PEMA). A range of disasters, natural and technological, occur annually in the Commonwealth of Pennsylvania. As is the case in most states, floods and fires dominate the disaster scene (see Figure 4.1).

Figure 4.1 Pennsylvania Presidential Disaster Declarations 1954-2004
It is important to note that Flood (52), Flash Flood (18), Winter Storm/Blizzard (12), Severe Storm/Tornado (10), High winds/Rain / Hail (8), Hurricane/Tropical Storm (7), and Flash Flood/Ice Jam (3) result from severe storms, and differ only by the time of year in which they occur and the strength of storm. Such storms account for 110 of the 174 disasters reported by the Pennsylvania Emergency Management Association (PEMA) for that 50 year period (source: PEMA: Pennsylvania Disaster History, 2004). Add to those 110 storms, the 38 fire related incidents, and the percentage of disasters due to storms and fire are 63% and 22%, respectively (85% of the total). The 10 other disasters recorded in the other category include a tire fire, truckers strike, refuse bank fire, mine flood, steam heat, nuclear incident (Three Mile Island) meltdown, gas shortage due to winter weather, power outage from snow, airplane crash, and a second airplane crash on 9/11/2001 that was categorized as terrorism.

An initial assumption about the role of GIS in Emergency Operations Centers was that GIS would be highly useful for planning and decision making activities in the hours leading up to a disaster (GIS would, obviously, also be useful after an event). Thus, rapid onset disasters such as fire (though wildfires and forest fires do exhibit a degree of slow development depending on the conditions of ignition and of the area in which they occur), industrial accidents or spills, earthquakes, and acts of terrorism were eliminated from consideration for onsite research.

Following this initial examination of disasters, contacts from PEMA helped to identify other emergency management experts with GIS backgrounds that could contribute to the study. The contacted participants agreed to complete a simple questionnaire (see appendix) about their tasks, activities, and use of geospatial information during crisis management. Participants were asked to complete and return the questionnaire via email within one to two weeks. The following section discusses the design of the questionnaire. The results and discussion of the questionnaire follow, then its effects on the bootstrapping process are discussed.

Questionnaires were developed to meet the following goals:

- to obtain a list of ‘typical’ emergency management goals, tasks and subtasks
- to establish a baseline working knowledge of the types of maps used and/or created in GIS for emergency management
- to determine the datasets required for task completion and map production
- to identify a general set of GIS operations used in multiple emergencies
- to narrow the focus of the study to a single disaster or crisis event
- to identify the types of tasks that could be used to create “Mission Scenarios” for onsite vitiations
- to help identify appropriate agencies for onsite visits
4.2.2 Preliminary Phone Interviews

The following scenario of the use of an emergency management GIS at national, state and local levels illustrates an example of a coordinated response to an approaching hurricane. The elements of this scenario were related by a respondent (an employee of the Center for Integration of Natural Disaster Information – CINDI) via an informal phone conversation in October, 2001. (Since the creation of the Department of Homeland Security, CINDI no longer exists, and employees have been folded into other government programs).

Emergency response situations require federal, state and local organizations to collaboratively assess the potential for disaster (such as a hurricane) to strike a given area. One type of activity would consist of the identification of critical facilities. States and agencies differ on the definition of what makes a facility critical, but in general, critical facilities are those buildings that are required for both the survival and recovery of a state. During an emergency response situation, federal agencies would combine hurricane tracking reports that include the past, present, and future movements of the storm. Buffer zones would be created around the regions (such as flood prone areas) where individual facilities are located that could be potentially in danger. The federal agency would then offload information to the individual state where local emergency managers would work to assess the impact the storm would have on the critical facilities through wind, rain or storm surges. Transportation and road networks, power plants, and similar types of data would be overlaid with the buffer zones, and regions where problems could arise could be identified, and workers would be deployed to help prevent the situation from spiraling into confusion. In such a situation, one or two counties might become overwhelmed by multiple problems (damaged hospitals, water intakes, etc), and need assistance. At such a point, the county’s workload could be offloaded to the state agency planning facility. The state agency could then reroute and reassign other county emergency response teams to the areas that are in disarray and ensure equitable and timely distribution of resources. When states become overwhelmed, they could defer to the federal agency for further assistance.

The activities related above required the coordination of real time satellite data with a standard GIS coverage. The responders also used GIS to locate features and to perform buffer operations and overlay operations on the available data. Numerous governmental and response agencies must also be contacted and provided with regular updates accordingly. This example describes a simple application of GIS use in emergency management.

To obtain more detailed information about GIS use, I recruited emergency managers from other federal and state levels of emergency management in Pennsylvania, Washington D.C.,
Florida and South Carolina. The participants were emailed questionnaires (in November, 2001) aimed at prioritizing and identifying the different tasks conducted by emergency managers that required maps, and the role of GIS, including the use of operations and geospatial data in emergency situations. A total of 12 participants were identified and agreed to participate in the questionnaire portion of the study. Four responded immediately, and a fifth response was received later.

4.2.3 Questionnaire: Preliminary Task Analysis

The primary goal at this stage of the research project was to obtain baseline information about emergency management tasks and GIS use within those tasks. The emailed questionnaires were sent to emergency managers at the following agencies: the Florida Emergency Operations Center, PEMA, the Pennsylvania Department of Environmental Protection (DEP), and CINDI. The managers ranged from top-level federal employees in administrative roles to county level GIS analysts. Participants were asked to complete two activities: task prioritization and task description. Also collected was information about the participants experience with hazards, GIS, and their job description and organization.

4.2.3.1 Task prioritization

The prioritization of emergency response tasks that relied on GIS was considered a necessary step in guiding the development of advanced information technologies for crisis management. The prioritization was also considered important in selecting the locations for onsite visits. The task prioritization was based on the Florida State Emergency Response Team (SERT) list of seventeen Emergency Support Functions (ESFs). ESFs are an organizational unit for coordinating emergency management resources from local, state and federal agencies. FEMA identifies 12 ESFs for disaster response. An example would be ESF 6: Mass Care. The lead agency for ESF 6 is the Red Cross, and the primary focus of operations is the management and coordination of relief provisions to victims. Individual states have created their own ESFs for state specific needs. Each ESF completes specific tasks to support all stages of disasters and crises. The Florida SERT ESFs are a variation on the ESFs recommended by FEMA (FEMA recognizes the first 12, and states have added others depending on their state specific needs and the organizational structure of the emergency management divisions). For response prioritization, the Florida classification was used because it represented a more detailed list (than FEMA’s) from which to identify tasks in emergency response (see Table 4.1).
To prioritize the tasks of ESFs that contained a significant mapping component, the questionnaire contained two questions regarding emergency management. The first question asked the participant to identify 4 functions (and their specific tasks for each of the 17 Emergency Support Functions in Table 4.1 that required extensive GIS use and map production.)
<table>
<thead>
<tr>
<th></th>
<th>FUNCTION</th>
<th>Task</th>
<th>Lead Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TRANSPORTATION</td>
<td>Provide or obtain transportation support</td>
<td>Department of Transportation.</td>
</tr>
<tr>
<td>2</td>
<td>COMMUNICATIONS</td>
<td>Provide telecommunications, radio and satellite support</td>
<td>Department of Management Services</td>
</tr>
<tr>
<td>3</td>
<td>PUBLIC WORKS AND ENGINEERING</td>
<td>Provide support in restoration of critical public services, roads and utilities.</td>
<td>Department of Transportation.</td>
</tr>
<tr>
<td>4</td>
<td>FIRE FIGHTING</td>
<td>Support detection and suppression of wildland, rural and urban fires</td>
<td>Department of Insurance</td>
</tr>
<tr>
<td>5</td>
<td>INFORMATION AND PLANNING</td>
<td>Collect, analyze and disseminate critical disaster information to State Emergency Response Team members.</td>
<td>Department of Community Affairs</td>
</tr>
<tr>
<td>6</td>
<td>MASS CARE</td>
<td>Manage temporary sheltering, mass feeding and distribution of essential supplies for disaster victims.</td>
<td>Department of Business and Professional Regulation</td>
</tr>
<tr>
<td>7</td>
<td>RESOURCE SUPPORT</td>
<td>Provide logistical and resource support to other organizations through purchasing, contracting, renting and leasing equipment and supplies</td>
<td>Department of Management Services</td>
</tr>
<tr>
<td>8</td>
<td>HEALTH AND MEDICAL SERVICES</td>
<td>Provide health, medical care and social service needs.</td>
<td>Department of Health</td>
</tr>
<tr>
<td>9</td>
<td>SEARCH AND RESCUE</td>
<td>Locate lost persons and victims trapped in collapsed structures and provide immediate medical care.</td>
<td>Department of Insurance</td>
</tr>
<tr>
<td>10</td>
<td>ENVIRONMENTAL PROTECTION</td>
<td>Respond to actual or potential hazardous materials discharges and other situations threatening the environment</td>
<td>Department of Environmental Protection</td>
</tr>
<tr>
<td>11</td>
<td>FOOD AND WATER</td>
<td>Secure bulk food, water and ice to support mass care needs</td>
<td>Department of Agriculture and Consumer Services</td>
</tr>
<tr>
<td>12</td>
<td>ENERGY</td>
<td>Support response and recovery from shortages and disruptions in supply and delivery of energy resources.</td>
<td>Department of Community Affairs</td>
</tr>
<tr>
<td>13</td>
<td>MILITARY SUPPORT</td>
<td>Provide military resources to support logistical, medical, transportation and security services.</td>
<td>Department of Military Affairs</td>
</tr>
<tr>
<td>14</td>
<td>PUBLIC INFORMATION</td>
<td>Disseminate disaster related information to the public.</td>
<td>Department of Community Affairs</td>
</tr>
<tr>
<td>15</td>
<td>VOLUNTEERS AND DONATIONS</td>
<td>Coordinate utilization and distribution of donated goods and services</td>
<td>Commission on Community Service</td>
</tr>
<tr>
<td>16</td>
<td>LAW ENFORCEMENT AND SECURITY</td>
<td>Coordinate the mobilization of law enforcement and security resources.</td>
<td>Department of Law Enforcement</td>
</tr>
<tr>
<td>17</td>
<td>ANIMAL PROTECTION</td>
<td>Provide rescue, protective care, feeding and identification of animals separated from their owners.</td>
<td>Department of Agriculture and Consumer Services</td>
</tr>
</tbody>
</table>

Table 4.1 Florida Emergency Support Functions
4.2.3.2 Task Description

GIS software applications provide a wide variety of operations (or functions) that support data storage, manipulation, and display (for example, Albrecht (1995) identified 144 different GIS functions). In an emergency response situation, it is likely that only a small subset of the total number of available GIS operations would be utilized. The second part of the questionnaire was developed to help identify some of the more common operations in order to help focus the design of the initial DAVE_G prototype.

The second section asked the following:

- for each of the ESF tasks identified in part 1, list the specific, step-by-step GIS procedures that support that task
- list the essential datasets required to complete the associated procedures and tasks, focusing on data exclusive to emergency management
- list the individual GIS operations required to accomplish the identified task

For example, if the chosen task the user selected was ANIMAL PROTECTION, participants were asked to provide a specific procedure related to animal protection such as, identify animal shelters outside of the impacted area, then to list the GIS commands (e.g. buffer operations, data queries, etc) and the datasets required to ensure the protection and rescue of the animals from the disaster event. This open-ended question was designed to allow respondents flexibility in their answers. This flexibility was considered important because participants included both GIS experts and geospatial information users. Thus, some participants did not actually use GIS, but instead, used geospatial information to make decisions and coordinate emergency response activities.

4.2.3.3 Participants

Four responses were received from state employees and one from a federal agency. Of the five respondents, two were employed in GIS related activities. Table 4.2 provides a basic profile of the participants. All of the participants were male. The numbers in the table refer to years of experience with GIS and emergency management experience (two of the five participants did not respond (no answer)).
4.2.3.4 Results of Task Prioritization

Results of GIS task prioritization for all emergencies helped to identify four primary tasks: provision of support for fire fighting, information and planning, search and rescue, and environmental protection. Each of these four tasks were selected by more than one participant (see Table 4.3 below). INFORMATION & PLANNING support received the highest overall ranking, and was indicated as important by three individuals, including both GIS specialists. Perhaps a reason for the selection by the GIS specialists is that the organizational structure of emergency management divisions places GIS workers in INFORMATION & PLANNING divisions. FIREFIGHTING support was identified by two participants as the second most important task. Respondents from the Pennsylvania DEP emergency management division both emphasized SEARCH & RESCUE support and ENVIRONMENTAL PROTECTION support, rounding out the ESFs receiving multiple votes. Of note is that the participant from CINDI emphasized PUBLIC INFORMATION support. CINDI was an organization that made GIS and maps available via the internet for emergency situations and did not take an active role in emergency response activities. Respondents were given the choice to select an OTHER category, and one participant chose this option twice, indicating that management and coordination of resource requests from counties, local municipalities and/or state agencies and mitigation and recovery operations during and after disasters were priority tasks 3 and 4, respectively.
4.2.3.5 Results of Task Description

Of the identified and prioritized tasks, respondents were asked to specify the procedures for completing the task, the required data sets and the specific GIS operations. As an example, the participants were given the ESF for Animal Support with the designated task to: *provide rescue, protective care, feeding and identification of animals separated from their owners.* Example procedures included: “identify large farms,” and “obtain proximity to relief assistance.” Example data included “county or state level ___ (i.e. roads),” and example GIS operations were “overlay of x and y,” and “buffer of x.” Individual results of participants are included below with summary tables following.

<table>
<thead>
<tr>
<th>Task</th>
<th>Title</th>
<th>Geographer</th>
<th>GIS Program Manager</th>
<th>Deputy Secretary for Management and Technical Services</th>
<th>Environmental Emergency Response Director</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TRANSPORTATION</td>
<td>PUBLIC INFORMATION</td>
<td>INFORMATION AND PLANNING</td>
<td>MASS CARE</td>
<td>SEARCH AND RESCUE</td>
</tr>
<tr>
<td>2</td>
<td>FIRE FIGHTING</td>
<td>no answer</td>
<td>COMMUNICATIONS</td>
<td>INFORMATION AND PLANNING</td>
<td>FIRE FIGHTING</td>
</tr>
<tr>
<td>3</td>
<td>INFORMATION AND PLANNING</td>
<td>no answer</td>
<td>Management and coordination of resource requests from counties, local municipalities and/or state agencies</td>
<td>PUBLIC WORKS AND ENGINEERING</td>
<td>ENVIRONMENTAL PROTECTION</td>
</tr>
<tr>
<td>4</td>
<td>HEALTH AND MEDICAL SERVICES</td>
<td>no answer</td>
<td>Mitigation and recovery operations during and after disasters</td>
<td>SEARCH AND RESCUE</td>
<td>ENERGY</td>
</tr>
<tr>
<td>5</td>
<td>ENVIRONMENTAL PROTECTION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 Task Prioritization
<table>
<thead>
<tr>
<th>Procedural Task</th>
<th>Task 1: Search &amp; Rescue</th>
<th>Task 2: Fire Fighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Required</td>
<td>Area impacted</td>
<td>Enter information on fire status: Controlled, out of control, extinguished</td>
</tr>
<tr>
<td>GIS Operations Required</td>
<td>Overlay on map.</td>
<td>Overlay on map.</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Environmental Protection</td>
<td>Energy</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Obtain location of release</td>
<td>Identify outages and shortages</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Identify material &amp; quantity released</td>
<td>Develop entry routes.</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Determine waterways affected if any, media affected via telephone reports, Conduct surveillance by ground observation &amp; flyovers</td>
<td>Deploy repair crews, Restore service, Obtain location and total area impacted by electrical or natural gas outage via telephone reports from customers or utilities.</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Determine transportation routes to scene</td>
<td>Locate and map energy supplies and fuel haulers.</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Deploy response team</td>
<td>Develop transport routes for fuel.</td>
</tr>
<tr>
<td>Procedural Task</td>
<td>Mitigate release.</td>
<td>Obtain location and total area impacted by fuel shortage via telephone reports from customers, governmental agencies or suppliers.</td>
</tr>
<tr>
<td>Data Required</td>
<td>Date, time, location, material released, quantity, media affected, contact person name, address, phone number, responsible party name address phone number, evacuations?, casualties?, cleanup contractor?, waterways affected, fire?, explosion? Material Safety Data</td>
<td>Name, address, phone, location of customers with service outage. Name, address, phone, location of energy supplier, Name, address, phone, location of auxiliary utility repair crews, status of crew i.e. Enroute, deployed, available, out of service, dismissed. Transport routes for utility crews. Status of service restoration.</td>
</tr>
<tr>
<td>GIS Operations Required</td>
<td>Overlay on map.</td>
<td>Overlay outages and shortages on map</td>
</tr>
<tr>
<td>GIS Operations Required</td>
<td>Enter information on status: terminated, cleanup required, cleared for occupancy.</td>
<td>Enter updated information on service restoration status on map.</td>
</tr>
<tr>
<td>GIS Operations Required</td>
<td>Enter information on map.</td>
<td>Enter updated information on fuel supply status on map.</td>
</tr>
<tr>
<td>GIS Operations Required</td>
<td>Enter information on fuel delivery status:</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4 DEP Emergency Response Director

90
<table>
<thead>
<tr>
<th>Geographer: USGS CINDI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task 1:</strong> PUBLIC INFORMATION - Hurricanes</td>
<td><strong>Task 2:</strong> PUBLIC INFORMATION, Earthquakes</td>
</tr>
<tr>
<td><strong>Procedures:</strong></td>
<td>Map of Epicenter of Earthquake</td>
</tr>
<tr>
<td>USGS emails hurricane bulletins to USGS managers and others on the email list when hurricanes are about to make landfall in the US</td>
<td></td>
</tr>
<tr>
<td><strong>Data Required:</strong></td>
<td>Latitude, Longitude, Magnitude, and Depth of earthquake from National Earthquake Information Center.</td>
</tr>
<tr>
<td>Tropical Prediction Center. Text file of forecast is copied from web.</td>
<td></td>
</tr>
<tr>
<td>Current and forecasted position (during the next 72 hours) of hurricane from National Hurricane Center</td>
<td>Base Maps (Topo maps: 1:250,000 to 1:25,000 scale, or state/country outline maps, Census data, fault maps)</td>
</tr>
<tr>
<td><strong>GIS Operations Required:</strong></td>
<td></td>
</tr>
<tr>
<td>Forecast is used in tables to created a point file of the current and forecasted position of hurricane.</td>
<td></td>
</tr>
<tr>
<td>5 concentric rings of 50 mi. diameter are created about the 72 hour position.</td>
<td></td>
</tr>
<tr>
<td>Locations of interactive stream gages and locations of USGS offices are also overlaid. JEPGs of the forecasted track of the hurricane are put into the bulletins and email to the subscribers.</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5 USGS Geographer - CINDI
| Deputy Secretary for Management and Technical Services: Pennsylvania Department of Environmental Protection |
|--------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| **Task 1: Mass Care** | **Task 2: Information & Planning** | **Task 3: Public Works & Engineering** | **Task 4: Search & Rescue** | **Task 6: Environmental Protection** |
| Identify facilities | collect, analyze and disseminate critical disaster information to state emergency response team members | Identify facilities | Establish search grid | Characterize disaster area |
| Proximity to disaster area | Characterize disaster area | Priority for restoration | Determine safe areas for search | Identify hazardous materials |
| Location of relief supplies | Arrange for imagery of site from archives and new targeting | Location of primary and supporting medical facilities | Establish safety zone | Identify public water intakes and air intakes |
| Location of suitable facilities for sheltering | Floodplains and streams | Extent of damage | Availability of resources to conduct search and rescue | Characteristics of area (residences, business commercial, industrial, etc.) |
| Location of adequate food supplies | Infrastructure (water treatment and sewage plants, distribution and collection systems) | Time to restore critical services | Mitigating issues (broken gas lines, stability of structures, etc.) | Surrounding infrastructure |
| Road Network | As built drawings of collapsed structures | | | |
| **Data Required:** | | | | |
| **GIS Operations Required:** | Generating available routes for movement of supplies | Show location of critical facilities (schools, nursing homes, hospitals, etc.) | Location of infrastructure and supporting network | In conjunction with GPS map search grid areas | Delineate area of plume |
| Overlay of population area from census data | Display road networks | Map extent of damage | Locate hazardous structures | Provides strip maps of area to responders along with location of buildings with other hazardous materials |
| Generating strip maps for emergency workers | | Location and routing of alternative support | Map evacuation routes for recovered injured individuals | Characterize population area |

Table 4.6 DEP Deputy Secretary for Management and Information Services
<table>
<thead>
<tr>
<th>Procedures:</th>
<th>Task 1: Transportation</th>
<th>Task 2: Fire Fighting</th>
<th>Task 3: Information and Planning</th>
<th>Task 4: Health and Medical Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify road closures</td>
<td>Show where fires are</td>
<td></td>
<td></td>
<td>Show where incidents occurred</td>
</tr>
<tr>
<td>Locate traffic congestion</td>
<td>Obtain satellite pictures (as recent as possible)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare for possible reversal of traffic (both sides go same direction)</td>
<td>Identify resources nearby</td>
<td>Establish staging areas</td>
<td>Identify potential Disaster Field Office sites</td>
<td>Identify potential at-risk population (nursing home, daycare center, etc.)</td>
</tr>
<tr>
<td>Data Required:</td>
<td>road networks</td>
<td>For wild land fires – show forest, wooded areas, hills,</td>
<td>Locations of the potential/designated buildings</td>
<td>Locations of nursing homes assisted living facilities</td>
</tr>
<tr>
<td>locations of critical intersection</td>
<td></td>
<td>For urban area fires – show potential hazards (gas storage sites, etc.)</td>
<td></td>
<td>daycare centers</td>
</tr>
<tr>
<td>locations of bridges</td>
<td></td>
<td></td>
<td></td>
<td>dense population areas</td>
</tr>
<tr>
<td>GIS Operations Required:</td>
<td>Show where these areas are</td>
<td>Overlay above data with streets, etc</td>
<td>Overlay data</td>
<td>Locations of health care facilities that can handle the above &quot;victims&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Buffer fires</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.7 Florida GIS Analyst
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinpoint area of concern</td>
<td></td>
<td></td>
<td>Management and coordination of resource requests from counties, local municipalities and/or state agencies</td>
<td>Deployment of personnel to support mitigation and recovery of communities affected by disasters or emergencies.</td>
</tr>
<tr>
<td>Display buffer if needed or requested to illustrate impact of emergency</td>
<td></td>
<td>Provide communications links between agencies and municipalities</td>
<td>Receive and disseminate resources to appropriate agencies</td>
<td></td>
</tr>
<tr>
<td>Identify municipality and population affected</td>
<td></td>
<td>Provide updates electronically to governor’s office and law enforcement agencies</td>
<td>Provide channels of communications for resource request along local, state and federal lines</td>
<td></td>
</tr>
<tr>
<td>Determine extent of damage</td>
<td></td>
<td></td>
<td>Coordinate and follow up resource requests</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Required:</th>
<th></th>
<th>State and local levels</th>
<th>Resource lists and capabilities on the local, state and federal levels</th>
<th>State and local data</th>
</tr>
</thead>
<tbody>
<tr>
<td>state and county levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>road networks</td>
<td></td>
<td>state and local levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>census tracts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>critical facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GIS Operations Required:</th>
<th></th>
<th></th>
<th>Display location and capability of resource</th>
<th>Overlay layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overlays</td>
<td></td>
<td></td>
<td>Contact information</td>
<td></td>
</tr>
<tr>
<td>Buffered zones</td>
<td></td>
<td>None at present</td>
<td>Buffer area including certain resources or needs</td>
<td></td>
</tr>
<tr>
<td>Locate critical facilities and resources</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.8 PEMA GIS Program Manager
4.2.3.6 Summary of Questionnaire Results

The identified tasks, GIS operations and data requirements are summarized below. In Table 4.9, a categorization of the types of tasks, the number of times they were identified, and the specific GIS functions required for completion are displayed. The numbers represent the number of distinct GIS tasks identified within each category, which is why there are more than 5 in a cell when there were only 5 respondents.

Not surprisingly, all respondents indicated that the most common activity for which GIS was used was information display (showing where something is in relation to another feature). In the table below, overlay operations appeared most (12 times), with layer display being mentioned 9 times. Buffers and the creation of specialized maps were the next most common identified uses of GIS. A caveat regarding the data is that in the questionnaire, participants were prompted with overlay and buffers as examples of GIS operations, and both categories were listed multiple times. The questionnaire wording might have biased the answers towards those operations. A final drawback could be a bias based on job functions (two respondents were from the same agency).

<table>
<thead>
<tr>
<th>Data Query / Information Retrieval</th>
<th>Geospatial Operations</th>
<th>Entry / Summaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relational Referencing</td>
<td>Information Display</td>
<td>Buffers</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Overlay Data Layers</td>
<td>Show / Display / Create Maps</td>
<td>Buffer [points, lines, &amp; polygons]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.9: Procedures and GIS Functions

A total of 41 procedures and their supporting GIS operations are summarized above. Specific examples that were aggregated include: determining the population of a particular area, displaying the location and capabilities of resources, locating critical facilities, obtaining contact information, generating available routes for movement of supplies, determining location and routing of alternative support, generating strip maps (of search areas) for emergency workers, mapping evacuation routes for recovered injured individuals, forecasting positions of hurricanes, merging GPS locations and search grid areas, mapping the status of recovery, showing areas
requiring cleanup, displaying regions cleared for occupancy, creating service restoration maps, mapping service outages, and tracking fuel supply and delivery status.

Carrying out even a subset of the procedures above would require a substantial amount of data. Respondents were asked about these data needs. The information is summarized in the following three tables according to three broad types: infrastructure data (all-purpose data not unique to a particular disaster); response related data; and hazard related information. The tables are not specific to a particular disaster type. Each table is broken down by point, line and polygon data types. Surprisingly, no image data sets were mentioned in the responses.

The geographic extent for desired data was primarily focused at county and state levels. One participant noted the need to store information about the estimated time to restore critical services. Integrating such dynamic data into the GIS represents an interesting challenge.

<table>
<thead>
<tr>
<th>Infrastructure (All Purpose)</th>
<th>POINT</th>
<th>LINE</th>
<th>POLYGON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Facilities (3): schools, nursing homes, hospitals, infrastructure, hazardous structures</td>
<td></td>
<td>road networks (4)</td>
<td>Characteristics of area (residences, business, commercial, industrial, etc.)</td>
</tr>
<tr>
<td>the current and forecasted position of hurricanes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surrounding infrastructure; location of bridges</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>earthquake epicenter</td>
<td>Transportation routes (4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>stream gauge locations</td>
<td></td>
<td></td>
<td>Census tract information</td>
</tr>
<tr>
<td>USGS office locations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locations of nursing homes</td>
<td>telecommunications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>assisted living facilities</td>
<td></td>
<td></td>
<td>dense population areas</td>
</tr>
<tr>
<td>daycare centers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cell towers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relay towers or centers</td>
<td></td>
<td>streams</td>
<td></td>
</tr>
<tr>
<td>locations of critical intersections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Law enforcement, fire and emergency services etc.</td>
<td></td>
<td></td>
<td>Floodplains</td>
</tr>
<tr>
<td>Military assets</td>
<td>supporting network</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.10: All Purpose Data Requirements
<table>
<thead>
<tr>
<th>POINT</th>
<th>LINE</th>
<th>POLYGON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability of resources to conduct search and rescue</td>
<td></td>
<td>Status of fuel delivery to customer or supplier (completed,</td>
</tr>
<tr>
<td>Resources (2)</td>
<td>Damaged transportation routes</td>
<td></td>
</tr>
<tr>
<td>Location of suitable facilities for sheltering</td>
<td></td>
<td>Evacuation areas</td>
</tr>
<tr>
<td>Hardware stores/distribution centers for disaster supplies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location of adequate food supplies</td>
<td></td>
<td>Census tracts</td>
</tr>
<tr>
<td>Status of crew (i.e. enroute, deployed, available, out of service, dismissed)</td>
<td></td>
<td>Status of service restoration.</td>
</tr>
<tr>
<td>Locations of the potential/designated buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name and location of fuel haulers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name, address, phone, location of auxiliary utility repair crews</td>
<td></td>
<td>Enter updated information on fire status on map.</td>
</tr>
<tr>
<td>Location and quantity of alternate supplies</td>
<td>Transport routes for utility crews</td>
<td></td>
</tr>
<tr>
<td>Name, address, phone, location of customers with service outage</td>
<td></td>
<td>Enter information on fire status: Controlled, out of control, extinguished</td>
</tr>
<tr>
<td>Name, address, phone, location of energy supplier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suppliers type and quantity of fuel shortage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name, address, phone, location of customers or suppliers needing fuel</td>
<td></td>
<td>Strip maps for search and rescue</td>
</tr>
</tbody>
</table>

Table 4.11: Response Related Data Requirements
4.2.3.7 Conclusions

The majority of the GIS operations identified by respondents involved showing and displaying different GIS layers and identifying specific locations on those maps. These initial findings guided development of the initial DAVE_G prototypes. Its functionality was focused on support for controlling display of multiple layers (show roads, show cities, display shelters) and map navigation tasks (pan, zoom in, zoom out, zoom here, scroll there). DAVE_G’s multimodal interface for supporting these functionalities and the technical aspects of their implementation are discussed in Rauchert et al. (2002) and MacEachren et al. (in press).

Emergency response activities vary significantly based on the type of emergency and are often correlated to the event’s temporal duration and spatial extent. Disasters and hazards can be slowly developing or rapidly unfolding. For example, some emergencies such as drought, nuclear particulate releases and even volcanoes can have a long lead time before evolving into disaster situations. In the case of a drought, its spatial extent would be large and temporal duration long, but the intensity and magnitude of response efforts would be relatively low when considered over the entire temporal duration of the event. Hurricanes have a shorter lead time before impact (sometimes more than one week or as short as a couple of days, but often around 96 hours).

During the preimpact period, response activities would be low and would gradually (and
sometimes rapidly) increase as the threat became apparent. After impact, the emergency management community’s response intensity would continue to increase depending on the amount of damage. The quickest disasters include acts of terror, fires, tornadoes, flash floods, etc. An industrial plant fire, for example, would have a small spatial extent, and compared to a hurricane, a short temporal duration. While the response intensity for individual first responders would be very high, the overall response activities would necessitate the need for federal, state and local government collaboration required to respond to a hurricane or a major flood.

A general characterization of each of these dimensions of emergency response appears in Figure 4.2. A high response intensity is related to the amount of mobilized resources required for a specific event. Examples of high intensity response would include massive collaborative and coordinated efforts that spanned the continuum of federal, state and county level organizations. Low response intensities would be representative of localized problems requiring only one or two agencies. Obviously, the placement of the disasters in the figure is for ‘typical’ events. Global climate change or a worldwide drought spanning decades and the resultant famine would obviously require a huge response effort, though the response effort would be diffuse geographically and temporally.
Given the information obtained in part 1, hurricane response was chosen as the focus for the remainder of the study. If opportunities had arisen for collecting more general information about emergency response activities for other hazards, that information would still have been collected in an opportunistic fashion however, the knowledge elicitation exercises were tailored to hurricane response. Each task selected by multiple participants (fire fighting, information and planning support, search and rescue, and environmental protection) also occurs during hurricanes.
Moreover, the other identified priorities: transportation, health and medical services, public information, communications, management of resources, mass care, public works and engineering and energy must also be supported during hurricane response. Hurricanes can also produce coastal flooding, inland flooding, tornadoes, power outages and thus require evacuations, sheltering programs, and farm animal relocation programs.

Hurricanes produce a wide range of hazards and require a massive integrated response. Because of this broad scope of destruction and response efforts for hurricanes, I hoped that in focusing on hurricane crisis management, I would also have the opportunity to collect generalized information related to other common disasters that are also associated with hurricane events (floods, fires, and tornadoes). Once hurricanes had been selected as the focus, the priorities of the offsite research shifted to gaining insight into the specifics of hurricane hazards, hurricane response and recovery operations. Section 4.3 outlines Part 2 of the bootstrapping techniques employed.

4.3 Part 2: Opportunistic Bootstrapping for Hurricane Response

With emergency management of hurricanes as the study’s focus, I shifted my efforts to the tasks of recruiting expert participants, identifying potential site visit locations, visit scheduling, and an opportunistic bootstrapping process to learn about hurricane hazards and the emergency response activities associated with that type of disaster. Efforts that aid knowledge collection in this process include document analysis, organizational diagram analysis, web-based searches, site profiling, course training, and literature reviews. The key distinction to note about this form of bootstrapping is that the process is self initiating and self perpetuating.

The initial information collection described in the previous section (including questionnaires and informal interviews) represents a method for developing a generalized understanding of emergency management GIS use in crises (not isolated to hurricanes specifically). Bootstrapping undertaken for this study included a literature review of hurricane hazards and GIS use in hurricane emergencies and completion of FEMA training courses in hurricane emergency management. Web searches of federal, state and local emergency response centers provided documentation and information about the activities and organizational structure of specific agencies. The first two stages of the bootstrapping procedure are discussed in the following subsections.
4.3.1 Review of Hurricanes Hazards

The following discussion is a review of the relevant literature as it pertains to two aspects of hurricane hazards. First, “hurricanes” are considered in terms of their physical characteristics within a global climate system. Second, “hurricane hazards” are discussed in terms of the intersection of these physical characteristics and the impacts of the hurricane on the infrastructure that societies value. Both of these characteristics influence the need for geospatial information and technologies.

When the physical world and human world interact through hazards, death, injuries and economic loss result. Often, specific historic hazards (e.g. Hurricane Andrew or Hurricane Floyd) represent a launching point for the study of hazards. Tobin and Montz (1997), suggest that case by case hazard analyses can provide detailed information about emergency management. Furthermore, recognizing that some of the issues transcend hazard events, they argue that only through the use of cross-hazard analysis can the similarities and differences be integrated into a comprehensive view of hazards – a theory of hazard studies. The hazard community has been criticized for lacking a comprehensive and explicit theoretical approach to hazard studies, with much of the research, though interdisciplinary by nature, being scattered, uncoordinated, and focused on single components of hazards to the exclusion of other factors (e.g. physical, societal, or economic dimensions of hazards rather than on their interrelatedness) (Tobin and Montz, 1997).

To help address this issue, Tobin and Montz (1997) created a framework that can help researchers follow an integrated approach to a comprehensive study of natural hazards. Their framework is composed of three dimensions, 1) the physical characteristics of natural hazards, 2) the political and economic factors of hazards, and 3) the social characteristics of hazards. They argue that these three areas combine to determine a community’s risk and vulnerability to a given hazard (Tobin and Montz, 1997).

However, just as politics serves to influence the building codes of a community, and thus, influence vulnerability, information technologies can also play a role in decreasing a region’s vulnerability. Therefore I have added a fourth dimension, 4) technology and disasters, to the framework advocated by Tobin and Montz (1997). The following sections discuss the hurricane hazards as they relate to the three dimensions identified by Tobin and Montz (1997) and to the additional dimension added here.

4.3.2 Physical Characteristics of Hurricanes

All hazards have specific physical characteristics. To discuss and represent the physical characteristics of a hazard, Tobin and Montz (1997) suggest that analyses focus on magnitude,
The magnitude of hurricanes in North America is often measured by the Saffir-Simpson scale (Figure 4.3). Hurricanes are ranked in the five categories based upon their sustained wind speed. Associated with that wind speed is the amount of damage to be expected by that category of hurricane.

<table>
<thead>
<tr>
<th>Saffir-Simpson Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category</strong></td>
</tr>
<tr>
<td>One</td>
</tr>
<tr>
<td>Two</td>
</tr>
<tr>
<td>Three</td>
</tr>
<tr>
<td>Four</td>
</tr>
<tr>
<td>Five</td>
</tr>
</tbody>
</table>

Figure 4.3: Saffir-Simpson Scale  (Source: the National Hurricane Center)

The magnitude of a hurricane influences the hazards associated with hurricanes. **Wind speeds** during hurricanes are among the strongest on earth, often only exceeded by the wind speeds of tornadoes. The threshold for a tropical storm to be considered a hurricane is to have one-minute sustained winds greater than 74 miles per hour at a height of 10 meters (Barnes, 1998a). Wind gusts within hurricanes can be much higher, and have been recorded at over 200 miles per hour. Within a hurricane, the sustained wind speeds increase until they reach their peak measurement near the eye wall of the storm. In regions with little topographic relief, hurricane winds can be sustained several miles inland, affecting regions that lie outside of areas with building codes developed to reduce the impact of these winds.

The **storm surge** is coastal flooding that occurs as a hurricane makes landfall; it is considered a hurricane’s most deadly force. A storm surge develops from strong, inward spiraling winds at the center of the low pressure system. The winds cause the ocean to form a
swirling column of water under the low pressure center. The column becomes a dome of water
that can be a few feet high in the center and range for over a hundred miles in diameter (Barnes,
1998a). When this column of water makes landfall, storm surges sometimes exceeding 20 feet
above sea level make landfall, often causing extensive damage to coastal areas. Storm surges are
augmented by high tides (and similarly, decreased by low tides). Local topography of the sea
floor, the type of coast, the presence of barrier islands, and the location of rivers and estuaries can
also influence the magnitude of storm surge. For example, the proximity of rivers to hurricane
landfall can lead to the creation of bores—high, abrupt tidal waves that sweep through the narrow
river channels (Barnes, 1998a).

**Inland flooding** from the rainfall produced by hurricanes represents a considerable threat.
**Torrential rainfall** also represents one of the biggest concerns for emergency managers.

The potential for evacuees to be caught in a traffic jam on an evacuation route and hit by
hurricane-force winds, inundated by a storm surge, or caught in a deluge of rainfall without
adequate sheltering represents a nightmare scenario for hurricane managers. For example,
estimates of an evacuation of the southern peninsula of Florida show that the evacuation of over
250,000 cars could take as much as four days (Barnes, 1998a). With hurricane warning and
prediction currently at a 36 hour range, and the forecast error at 110 miles, the potential for
individuals to be stuck in their vehicles as the storm makes landfall is high. Neil Frank, the
former director for the National Hurricane Center identifies such a scenario as the worst possible
outcome from a future hurricane (Barnes, 1998a).

There are other major factors that can affect the hurricane’s intensity that are included on
the Saffir-Simpson scale: tidal movements, local geography, orientation, forward speed, and
diameter (Barnes, 1998a; Barnes 1998b), each with unique impacts for a land-falling hurricane.
For example, forward momentum of a hurricane as it reaches a coastline can contribute to the
severity of the storm surge and wind damage. The total wind speed of a hurricane is a
combination of the rotational winds coupled with the forward movement of the storm. A fast
moving hurricane would bring higher winds to the right quadrant of the storm and reduced winds
on the left side of the storm, whereas slow-moving hurricanes would have lower wind speeds, but
would bring about more torrential rains (Barnes, 1998a). Generally, in the lower latitudes of the
Gulf Coast, the forward movement of hurricanes averages about 15 mph (Barnes, 1998a).

The frequency of hurricanes varies annually. Each year, approximately sixty tropical
waves form in the Atlantic, Caribbean, and the Gulf of Mexico (Barnes, 1998a). On average,
only ten storms reach tropical storm intensity with six reaching hurricane strength. The United
States coastline is struck by an average of more than three hurricanes every two years between
Texas and Maine, with the greatest frequency of hurricanes (40%) making landfall in Florida (Barnes, 1998a). William Gray, a meteorologist at Colorado State has been studying the frequency of hurricanes for decades and is considered the authority on long-range hurricane prediction for the United States. His research involves analyses of El Nino-Southern Oscillation variations (Gray 1984), the stratospheric Quasi-Biennial Oscillation (Gray, 1984), North Atlantic sea-surface temperature patterns, and West African rainfall patterns (Gray, 1990; Gray and Landsea, 1992) as precursors to predicting hurricane landfall along the US Atlantic Coast. Other global change studies (Glantz, 1996; Gray et al, 2001)) have identified links between El Nino, its influence on global weather patterns, and the affect to US Hurricane frequency.

For instance, Gray et al (2001) predicted increased hurricane activity in the United States in the past several years. Gray’s predictions suggested that 2002, 2003, and 2004 should have above average years for hurricane frequency. Although hurricane frequencies were above average overall, Gray’s predictions for US landfalls fell short for 2001-2003, but not in 2004.

Not all hurricanes are created equally. To better understand how a hurricane will affect the coastal region, and to make predictions about its impact, it is important to understand the spatial dimensions of hurricanes (see Figure 4.4). While the Saffir-Simpson scale is useful for understanding the wind speed and damage of a hurricane, it tells nothing of the spatial reach or the spatial distribution of the most powerful portions of the hurricane. McKnight (1996) reports that hurricanes range in size from 100 to 600 miles in diameter and that hurricanes originating in the Atlantic or the Gulf of Mexico tend to have a similar structure. Generally, the eye of Atlantic hurricanes has a diameter ranging from 10 to 25 miles across and an eye wall height of 10 nautical miles (McKnight, 1997).
Hurricanes have a strong seasonal component, forming only when the ocean has reached a sufficient temperature. In late summer-early fall, the tropical ocean temperature reaches its peak, causing an increase in tropical storm activity. August, September and October are the most common months for Atlantic Hurricane formation (with September having the most major hurricanes and September 10-20 being the peak period in the seasonal cycle), but officially, the hurricane season stretches from June 1 through November 30 (Barnes, 1998a). Six conditions are necessary for hurricane development: 1) an extensive ocean area with a surface temperature above 79°F; 2) a location at least 4 or 5 degrees from the equator; 3) wind speed and direction changes between the lower and upper troposphere of less than 15km, 4) a distribution of temperature with height that will overturn when saturated, resulting in cumulonimbus clouds; 5) anticyclonic rotation in the upper troposphere; and 6) the presence of a tropical wave disturbance or some other means of generating synoptic-scale cyclonic rotation; (Pielke, 1990; Tobin and Montz, 1997; Pielke and Pielke, 1997).
The countdown interval in natural hazards research refers to the speed of an event’s onset (Tobin and Montz, 1997). Rapid events create unexpected situations that can tax emergency managers’ short and long term response and mitigation strategies. Historically, hurricanes had short countdown intervals, but modern technological advances, such as Doppler radar, Hurricane Hunter aircraft data, and better models of storm prediction have increased the countdown interval of hurricanes to several days. Tobin and Montz, (1997) report that the 24 hour forecast for hurricane landfalls in North America improved by 15 nautical miles since 1954, but the current average error (at the time of their writing) was still well over 100 miles. The forecast error is due to several sources of uncertainty. For example, hurricane movement is dependent upon 1) large scale regional air patterns, 2) internal storm forces, and 3) the outflow jets from the storm (Tobin and Montz, 1997). Another source of uncertainty in forecasts is the size of the hurricane (e.g., a smaller storm is more affected by changing meteorological systems and topographic features at landfall). Hurricanes can also develop rapidly or dissipate quickly; these uncertainties in landfall affect decision making efforts of emergency managers.

### 4.3.3 Political and Economic Aspects of Hurricane Hazards

Emergency managers are increasingly becoming better prepared to forecast, warn, and mitigate the physical aspects of hurricane hazards. Because of the uncertainty associated with natural hazards, however, it is often difficult to predict and understand the political and economic aspects of hazards. Political and economic elements of hazards have been broken into two major categories, individual and societal, in the framework proposed by Tobin and Montz (1997). To summarize the components of these two aspects see Table 4.13.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Societal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximity to the hazard source</strong></td>
<td><strong>Land use patterns</strong></td>
</tr>
<tr>
<td><strong>Type of structure</strong></td>
<td><strong>Distribution of wealth</strong></td>
</tr>
<tr>
<td><strong>Level of empowerment</strong></td>
<td><strong>Resource management patterns</strong></td>
</tr>
<tr>
<td><strong>Range of choice</strong></td>
<td><strong>History and the level of development</strong></td>
</tr>
</tbody>
</table>

Table 4.13 Individual and Societal Issues in Hazard Management

The role of public policies in hazards is influenced by a society’s perception of the policy and is coupled with a society’s ability to prioritize policy changes and economic resources on the local political scene. Collaboration and cooperation among policy makers and response agencies is necessary to develop the solutions and strategies for implementation and mitigation.

Economic conditions influence the funding available to respond and recover from emergencies. National, state and local cooperation and collaboration is necessary for effective hazard management, and changes to existing systems often require extensive policy changes in
order to redistribute the available economic resources. Emergency decision makers must be able to assess, in real time, the scope of a disaster, including spatial location, spatial extent, casualty levels, and estimates of infrastructure and property damages and to determine how these elements are related to the population of a given area and to the jurisdictional boundaries (NRC, 1999).

Policies need to dictate that hurricane warnings be more precise and detailed to help people in highly vulnerable locations. People in cities as well as remote or rural locations must have robust communication and hazard notification systems. Evacuation routes must be identified and optimized to minimize traffic congestion and prevent gridlock (NRC, 1999). Coordination among the local response and recovery efforts is necessary for delivery of relief supplies. Crisis response personnel must be provided with appropriate maps and position location aids during all phases of emergency response (NRC, 1999). Damage surveys of essential local infrastructure must be produced, and repairs must be prioritized and funded rapidly for long term recovery operations (NRC, 1999).

4.3.4 Social Elements of Hurricane Hazards

Individual decision making can have significant influence on the behavioral response of an affected society. Tobin and Montz (1997) identify four stages of individual decision making activities. Individuals should: 1) appraise the probability and magnitude of the hazard, 2) consider a range of actions based on experience 3) evaluate the consequences of these actions and 4) make a decision of one or more actions to take.

Often, an individual’s perception (or lack of perception) of risk determines whether or not action is taken. A hurricane risk perception study was conducted by Neil Frank when he was the director of the National Hurricane Center. Posing as an out of state investor, he visited condominiums along the Florida coast and asked each of 75 property salespersons whether or not they had a hurricane problem. Only two of them answered yes, while the remainder of the respondents had never experienced a hurricane (Frank in Barnes, 1998a).

Experience plays a significant role in a perception of risk (Cutter, 1993). Frank points out that most residents of Florida and other coastal regions threatened by Hurricanes have never experienced a hurricane, therefore their individual perception of risk is significantly reduced (Frank in Barnes, 1998a). Tobin and Montz (1997) indicate that the residents of south Florida who did not evacuate when Hurricane Andrew approached were making rational decisions based on personal experience with hurricane landfall in their region; however, their decisions not to evacuate placed them in significant danger. Individual and societal denial that hazards exist can also affect decision making in disasters, and such decisions affect emergency response efforts.
The decision to evacuate can be contentious for families. For instance, individuals must weigh the costs of leaving their residence vulnerable to looting versus attempting to weather the storm to protect their personal property. In the days leading up to Hurricane Andrew, individuals who chose to stay behind prompted law enforcement and emergency management officials to order forced evacuations (Tobin and Montz, 1997). Tobin and Montz (1997) argue that behavioral and personal preference studies need to be conducted in order to fully understand the role of individuals in emergency situations such as an evacuation. Moreover, they stress the need for characterizations of the impact of sociocultural factors (e.g. education, employment, income, religion and family ties) on individual responses to disasters.

To reduce a community’s vulnerability to a disaster, the hazard must be identifiable and recognized as a threat to civil society and individuals involved, the decision makers must be aware of potential mitigation strategies, and there must be a common will to act. Tobin and Montz (1997) point out that an important factor for crisis managers to consider is that during a hurricane’s aftermath, communities tend to come together to work against the threat that is perceived as being from outside of their control. This phase of recovery lasts until a state of normalcy is reached, at which time community togetherness is returned to its previous state, and the perception of risk again is diminished. The following sections highlight important technologies and technological developments for reducing vulnerability and responding to hurricane hazards.

4.3.5 Technological Aspects of Hurricane Hazards

4.3.5.1 Geospatial Information Technologies in Emergency Response

Disastrous situations have forced society to adapt and utilize new technologies for emergency management. Often, critical incidents provide the spark for the infusion and development of these new technologies. For example, the 2001 terrorist attacks in New York City and Washington D.C. prompted a new wave of policy, organizational, and economic changes to emergency management in the United States. These policies have increased funding to academia, private business, and response agencies nationwide supporting training programs, technology development and research focused on protecting communities and improving homeland security. In the past, large natural disasters have driven the development and adoption of new technologies. The extensive destruction wrought by hurricane Andrew prompted hurricane management and response reform, specifically in the widespread adoption of GIS technology (Dash, 1997). To understand the role of geospatial information technologies in emergency management today, the following discussion will use Hurricane Andrew and Hurricane Floyd as benchmarks for examining the redevelopment and evolution of GIS and
Information Technology (IT) in emergency management. The discussion will be separated into the role of GIS before Hurricane Andrew, after Hurricane Andrew, and during and after Hurricane Floyd.

4.3.5.2 Geospatial Information Technologies before Hurricane Andrew

In the 1970s, traffic flow modeling for urban evacuation, fire spread modeling, prediction of weapons effects and economic recovery modeling were among the first pilot studies to utilize GIS technology for emergency management (Stephenson and Anderson, 1997). Stephenson and Anderson (1997) indicate that in the early 1980s, the utility of computers for real time emergency information management was in its infancy, with developments in decision support systems for emergency management and the use of GIS for risk projection being noteworthy examples. They suggest that GIS emerged as a credible technology for emergency management in the late 1980s when it was used to produce evacuation simulations for industrial hazard response, enhanced by mapping outputs and graphic displays (Stephenson and Anderson, 1997). Stephenson and Anderson (1997) point out that adoption and implementation of GIS technologies was slowed by the expense of workstations and the limited development of software packages. However, they suggest that the introduction of new microprocessors along with ARC-Info and MapInfo software programs allowed the initial users to envision a range of possibilities of GIS in emergency management support for mitigation, response, and recovery.

4.3.5.3 Geospatial Information Technologies after Hurricane Andrew

In the early 1990s, several new Emergency Operations Centers were established nationwide, prompting a growth in the interest of GIS technology. Much of the initial work focused on earthquakes (Stephenson and Anderson, 1997). A significant change in the role of GIS followed Hurricane Andrew in August, 1992. Andrew was a strong category 4 hurricane with wind gusts over 175 mph that decimated Dade County, Florida and forced the evacuation of over 700,000 people (Barnes, 1998a). Economically, Andrew was the costliest storm in US history, with over $30 billion dollars of damage to the regions falling within its 25-30 mile wide path. The use of GIS during the recovery process from hurricane Andrew represented a benchmark for the integration of GIS and disaster response and recovery. Initially, GIS use was for mapping damage and for analyzing community dynamics (Dash, 1997). Once GIS’s potential was realized, its use began to spread into public assistance and hazard mitigation programs.

FEMA and the state of Florida adopted MapInfo as the GIS package to support these activities, and began to integrate datasets, and track debris removal, identify damage, secure abandoned homes, and determine the location of trailers for temporary housing (Dash, 1997). Other data were integrated, including evacuation zones, hurricane shelter locations and
Dash (1997) argues that the critical lesson learned during hurricane Andrew was the need to implement a GIS program before, not after an event. For example, in the response to Hurricane Andrew, Dash (1997) states that the first GIS product took four months to produce. Post-Andrew, GIS development efforts shifted towards preparedness and proactive development of GIS programs in emergency management divisions. Dash (1997) points out that in the response to Hurricane Andrew, GIS were used primarily to show and display specific data, and the responders did not utilize the analytical and spatial power of GIS software.

Coppock (1995) and Dash (1997) report that GIS support in emergency and natural hazard management and response remained limited in the mid 1990s (with FEMA’s use of GIS after the Northridge Earthquake being a notable exception (Stephenson and Anderson, 1997)). Despite some of the earlier successes in GIS implementation, in the mid to late 1990s, GIS was still not established as a widespread decision support tool in emergency management. The slow acceptance of GIS as a practical tool for crisis management was likely linked to data issues. Efforts at establishing spatial data standards among federal, state and local emergency management agencies were in their early stages, and most of the data available had not yet been updated, leaving responders with unusable geographic data (Dash, 1997). Dash (1997) presented a research agenda for the effective use of GIS in emergency management, requiring 1) identification of the extent that GIS and decision making technologies had been implemented, 2) investigations about how the systems were being used as decision making and information dissemination tools, 3) identification of who is using the technologies, and 4) discovery of whether state and local stratification was occurring between those with GIS technologies and those who relied on other agencies (the haves and have-nots). Dash also advocated the use of GIS to study the social, economic, and political aspects of disaster both before and after events through the use of surveys and demographic data. Finally, Dash (1997) argued for the use of GIS in vulnerability analysis.

4.3.5.4 GIS and Hurricane Floyd (source USNOAACSC, 2001)

Hurricane Floyd made landfall in North Carolina on September 15, 1999 and the NOAA report cited above suggests that it was the first time that federal, state and local agencies relied heavily on spatial data and GIS technology. Agency preparedness activities relied on GIS mapping and spatial analysis techniques to provide flood potential forecast maps, disseminate forecasts, monitor and track real time road conditions, and identify locations of damaged areas.

As with hurricane Andrew, GIS was used most extensively for the long term recovery phase. FEMA established a Regional Operations Center in response to Hurricane Dennis in 1999
that stayed in service through Hurricane Floyd. FEMA requested that the U.S. Army Corps of Engineers (USACE) assess the use of GIS during the response and recovery stages of both hurricanes. The USACE reported that GIS received limited use due to the lack of knowledge by Regional Operations Center personnel of the capabilities of GIS, a small GIS staff, and non-user friendly data organization. Despite the limited use, GIS proved to be effective in the response and recovery efforts. The remainder of this section highlights some of the seminal achievements in GIS use for hurricane response outlined in the report.

GIS was utilized to provide the emergency managers at the regional operations center with maps depicting storm track forecasts, precipitation forecasts, real-time river gauge data, forecasts of river peak crest elevations and locations, critical transportation routes, and demographic distribution data. Multiple data sets were combined to provide estimates of significant damage impact areas through predictive modeling. GIS analysts integrated demographic data, road network data, critical facilities, infrastructure, and emergency shelter locations to decide where 23 Disaster Recovery Centers should be located. The USDA used GIS products to identify low income areas likely to be impacted by Hurricane Floyd, allowing advanced planning on the distribution of emergency food stamps by a social service organization. The US Department of Transportation was able to provide real-time highway evacuation status data to GIS personnel working in the Information and Planning ESF. Traffic flow conditions on major evacuation routes, and roads left impassible due to flood inundation or debris, were displayed using US DOT information combined with other GIS data sets.

Flooding resulting from Hurricane Floyd rendered thousands of North Carolina residents homeless. FEMA and the state of North Carolina created several temporary housing facilities for affected individuals near the flooded areas, while ensuring the facilities were outside of the floodplain, separated from endangered species habitats, and established on suitable soils. GIS was used to integrate data (floodplains, endangered species habitat locations, soil types, archeological sites, substantially damaged locations, land uses, and road networks) and produce response and recovery maps.

At the state level, North Carolina used GIS to rapidly portray damage information to legislative officials, demonstrating the impact and spatial extent of the situation. Also, the threat of Hurricane Floyd created the largest peacetime evacuation in U.S. history (USNOAACSC, 2001). Collaboration amongst all federal, state, and local emergency management agencies, law enforcement agencies, and the North Carolina Department of Transportation required real-time road condition information (e.g. status, traffic volumes) distributed through web based maps. Other achievements ranging from state to local level are documented in the USNOAACSC 2001
Lessons Learned from Hurricane Floyd (source USNOAACSC, 2001)

Poor planning, cooperation, and collaboration were the biggest impediment to widespread and more effective use of GIS technology by federal, state and local agencies. The report stressed that there was a lack of pre-planning that limited the utility of GIS. This lack of planning led to unorganized data, underutilized data, lack of knowledge about existing data, and poor data dissemination. A significant amount of time was spent cleaning and reformatting data. Satellite and digital aerial imagery could not be integrated. There was poor communication regarding the collection of needed satellite imagery. Moreover, different agencies used multiple projection systems and GIS software packages, causing significant delays and data reformatting. The satellite imagery acquired did not coincide exactly with peak flood stages yielding under representation extent of flooding damage and all data lacked any information regarding flood depths, preventing an understanding of the magnitude of flooding. Furthermore, flood insurance rate maps were out of date.

The report further stressed the prevalence of poor interagency collaboration. For example, a real-time traveler information web site had to be created after Hurricane Floyd made landfall. Rural water and sanitary sewer information was used by multiple agencies, but no single agency controlled its management. There was no data available identifying the locations of the historic properties. The North Carolina Ferry Division did not communicate with NC DOT. GIS data servers were shut down to prevent damage when they were most needed. Interoperability amongst software packages remained a problem hindering federal to state level collaboration. Digital aerial photography data were not properly aligned. 25-meter and 50-meter resolution satellite data were merged into single visualizations, preventing accurate analyses. There were no data collection protocols for georeferencing and all agencies lacked real-time, accurate flood predictability visualizations. Moreover, multiple agencies reported road closings, leading to conflicting data about whether road closures applied to emergency vehicles or only civilian traffic. Both the state and FEMA set up individual local area networks (LANs) hindering data sharing. County agencies lacked detailed emergency response and recovery plans, including contingency plans for the flooding of GIS centers. The issues of data collection, data verification, and data maintenance and interoffice/interdepartmental cooperation and collaboration remained significant barriers to effective emergency management.

4.3.5.5. Geospatial Information Technologies Today

Dash (1997) proposed a classification of use for hurricane management into five major areas. First, GIS is useful for problems dealing with location. For example, a GIS can answer questions such as, “where is the emergency operations center located?” Secondly, GIS are useful for answering conditional questions that meet certain criteria. In the case of hurricane management, a typical question might be, “how many roads lie within the coastal flood zone?” A third type of question GIS can assist with is the identification of historical trends. Following on the hurricane theme, an analyst might determine historically flood prone regions over multiple storm events. Knowing this information, he/she can predict areas that will likely flood for a given storm size and track. Such information is important for predicting evacuation zones and making accurate damage estimates. Fourth, GIS can be used to identify spatial patterns to ask questions
such as, “what income groups were affected by the wind damaged region?” Finally, GIS can be used to help model scenarios of the storm’s potential impact. To illustrate the latter point, an emergency management GIS has the potential to help decision makers ask a question like, “if this Interstate is damaged, how will disaster relief be disseminated?” Another question might be “what will the hurricane’s damage affects be if it makes landfall 30 miles east of a given location?” A key element that GIS provides to emergency managers is an ability to integrate physical, political, economic, and social geographic data in order to understand hurricanes as holistic phenomena. If these elements are integrated into an organization’s GIS, they could potentially help reduce a region’s vulnerability (e.g., Wu et al., 2002).

This section has examined the role of information technologies as an independent dimension of study in disasters and hazards. The design of GIS and information technologies for hazard management could potentially benefit from an integrated approach that builds on Tobin and Montz’s (1997) identified dimensions (understanding the political, economic and social factors) while giving equal attention to a fourth dimension, information technologies. Such a strategy could help improve the understanding of geospatial information use as well as the development and design of GIS, visualization, and collaborative technologies to support mitigation, planning, preparedness, response, and recovery activities in emergency management.

4.3.6 Online FEMA Certification in Hurricane Emergency Management

In addition to the above activities, the bootstrapping process I carried out included enrolling in online courses in emergency management offered via the FEMA website. It is important for field researchers to know the subject matter so that the expert does not have to spend time explaining basic terminology and functions of their job. For hurricanes, for example, certain tools are used by nearly every agency. One such tool, HURREVAC, allows specialists to download and display National Hurricane Center (NHC) watches and warnings, local weather information, storm forecast tracks and evacuation time predictions for coastal areas. The software helps emergency managers estimate storm surge, wind speed, and strike probabilities based on the latest forecast advisory. HURREVAC was introduced in a FEMA training course that I completed. The course, IS-324 Community Hurricane Preparedness (FEMA, 2004), was designed to prepare decision makers with the information related to hurricane formation, hurricane hazards, National Weather Service forecasts, and the tools and information that decision makers need to prepare and respond to hurricanes in their communities.

The course was broken into four sections: (1) basics of hurricanes; (2) hurricane hazards; (3) forecasting (processes and uncertainty) and (4) decision making. In the basic section, the course discussed hurricanes and their physical structure including season, origin and observation.
Then it emphasized the hazards (storm surge, high wind, heavy rain, and tornadoes) associated with hurricane landfall. In forecasting, the distillation of forecasters’ summaries was emphasized as it related to hurricane landfall – with most emphasis on uncertainties and probabilities in forecasting depending on how many hours it was from landfall. Within decision making, key aspects were identification and creation of individual community hurricane Emergency Operations Plans (EOPs). These plans detail the activities, the responsible parties, and the time for completing response activities.

Also included in the course were video interviews with top hurricane officials in FEMA, county level emergency managers and public safety directors describing the decision making process for hurricane events. The course also provided insight into the structure of hurricane response decision making. "Time Delineating Schedule (TDS) for Storm Emergencies," prepared by the Lee County, Florida Emergency Management Division provides a general guideline of decision making activities during response (Table 4.14 below).

| Awareness: | Notify people of the impending storm |
| Standby: | Prepare emergency services |
| Decision: | Decide if and when to evacuate |
| Preparation: | Place resources into position |
| Evacuation: | Evacuate |
| Storm Event: | Take shelter and begin assessing needs |
| Evaluation: | Assess the emergency and respond |
| Recovery: | Rebuild and plan for the future |

Table 4.14: Time Delineating Schedule Implementing EOPs (Source, FEMA, 2004)

The training course provided the opportunity to learn the basics of hurricane emergency response and provided the above structure of the nature of hurricane response decision making. The course emphasized two elements that significantly constrain the decision making process: the uncertainty in landfall place and time, and the location dependent amount of time required for evacuations to complete in advance of tropical storm force winds (both geographic issues for which geospatial information and GIS are important.

4.4 Impact of findings on Stage II

The bootstrapping process yielded detailed information about the diversity of technological advancements in response across states and counties and the spatio-temporal variability of hazards and decision making in hurricane disasters. The information learned influenced the design of knowledge elicitation questions and prompts as well as the specific
techniques for onsite knowledge elicitation sessions. The next few sub-sections highlight key issues that affected the selection of sites and techniques for onsite work.

4.4.1 Established GIS Infrastructure

Since the primary objectives of this research are to understand how GIS are used currently in crises and to inform and prompt envisioned designs and improvements to existing GIS, agencies selected for recruiting had to have an established program for GIS and/or geospatial information technologies. Not only did the agencies need to have a GIS infrastructure but they also had to be willing to commit personnel and resources to the study for several hours spread out over multiple days. For the most part, locations were selected based on advice from interviewed experts about the GIS capabilities in specific counties and states.

4.4.2 Presence of an EOC

Emergency management officials and decision makers direct and coordinate response activities in Emergency Operations Centers. EOCs typically have large screen displays and conference rooms where decision makers hold meetings, congregate around either static maps or projected maps, and collaboratively discuss the impending disaster. Since the prototype to DAVE-G was built for use with large screen displays, understanding work with such displays at these locations was identified as a priority. Observing the decision makers in their work environments was also an important goal.

4.4.3 Collaborative Activities and Geospatial Information

Emergency response is a highly collaborative activity, involving multiple people and organizations. Therefore, it was important to find organizations with multiple participants who collaborate with one another during emergency response. Specifically, the goal was to uncover the degree to which collaborative activities influence or hinder the use of GIS in emergency response. Information about the interactions among national, state and local agencies, inter and intra-agency interaction, and command center interaction with emergency response teams represented the target for uncovering collaborative decision-making activities.

4.4.4 Availability

The availability of experts and their willingness to commit the time and resources for participation was a crucial element. Based on these considerations, the following organizations were contacted and agreed to participate in onsite visits.

- Florida State Emergency Response Team in Tallahassee, Florida
- South Carolina Emergency Management Division in Columbia, South Carolina
- Director of Public Safety in Horry County, South Carolina
- Emergency Management Director in Charleston County, South Carolina
The state level organizations agreed to participate for multiple days with multiple personnel involved. The county level organizations agreed to two hour meetings with the potential for follow up depending on the results of the initial meeting. The North Carolina Division of Emergency Management, FEMA Region IV Hurricane Director’s office and the Hurricane Liaison Team, the National Hurricane Center, and Miami County EOC also indicated a willingness to participate, but scheduling constraints and the onset of wildfire and hurricane season prevented inclusion of these organizations.

4.5 Thoughts and Conclusions

The goal of Stage I in the CTA was to develop a base level understanding of emergency management and to select the type of emergency situation for focused onsite knowledge elicitation sessions. The information about GIS use from the questionnaire also benefited the DAVE_G development team. From this initial questionnaire, a simple set of GIS commands were compiled and integrated into the first DAVE_G prototype. The questionnaire method was employed because it was a relatively quick method for obtaining qualitative data about simple emergency management tasks and the use of GIS during crises. Despite the small number of participants, the information collected was adequate to make a decision to focus on hurricanes for the remainder of the research project.

Questionnaires helped to identify cases of “typical use” of geospatial information technologies during emergency management. At this stage, the priority was to select a single disaster that would be representative of the use of GIS in emergencies, and also have enough flexibility to handle tough case situations and unforeseen elements that would require time-critical decision making in crises. By identifying the standard GIS functionalities and base datasets for emergency management, early advances were made on the prototype DAVE_G system so that the software developers and programmers could begin to implement the minimal set of functionalities required for an emergency response system. Rauchert et al. (2002) derived the following functionalities from the initial results of the questionnaire.
The questionnaire provided useful information related to the development of the prototype. Specifically, the preliminary information was adequate to provide basic design goals for the technology development teams, and to identify the task and the organizations that would serve as the main participants for the design of future scenarios of emergency management use in crisis situations. The information is further distilled into the Table 4.16. This classification does not focus on gesture speech inputs, but instead emphasizes those commands used in GIS activities during all emergencies. There are four major categories across the top, with subcategories underneath that depict specific map related tasks. As Davies (1995) and Dash (1997) found in their studies of work with GIS, most of these commands are largely generic GIS operations, with little use of the deeper analytical processing tools available in GIS technology. The most common uses of GIS as related here dealt with the simple display and presentation of basic spatial information.

<table>
<thead>
<tr>
<th>Command Type</th>
<th>Data Query</th>
<th>Viewing</th>
<th>Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>show/hide layers, buffers</td>
<td>scroll left/right/up/down</td>
<td>circle</td>
</tr>
<tr>
<td></td>
<td>spatial, with gestures</td>
<td>zoom in/cut/full extent</td>
<td>line</td>
</tr>
<tr>
<td></td>
<td>attribute, without gestures</td>
<td>center at</td>
<td>free-hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>zoom area</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.15 DAVE_G Supported User Commands (from Rauchert et al., 2002)

Table 4.16 Initial Geospatial Information Typology Stage I

A recognized, yet acceptable drawback to the questionnaire approach is that there were there too few participants, and also the answers from the users were often very brief. Moreover, each respondent answered questions differently than the others, therefore complicating data aggregation. As a stand alone technique, questionnaires can provide only a limited degree of
feedback; however, if followed up with interviews and meetings, the questionnaire approach can provide vital initial feedback, especially when dealing with situations that are unfamiliar to the system developers.

The approach could be potentially improved with a few changes. The Task Prioritization was aimed at obtaining a broad range of information from multiple emergency response agencies. Because of this decision and the small number of responses, the data can only be examined at face value. However, if a similar questionnaire were applied again, this time using the recently redefined ESFs mandated by FEMA, and given to a large number of individuals in multiple state agencies, more generalizable information might result. Instead of focusing on tasks for which GIS is used, the prioritization could be presented in the form of questions such as ‘indicate the ESF that requests the most map products’ and ‘indicate the ESF that requires the use of X (i.e. buffer) GIS function.’ Even with this approach, results will be influenced by the fact that the use of maps and GIS will vary by disaster. Thus a further variation that might yield more informative results would be to prioritize ESF functions (and the role of maps and GIS in supporting them) by disaster (e.g., for nuclear particulate release, prioritize the ESFs responsible for dealing with response). Similar variations could be completed for a variety of disasters as well as the range of mitigation, preparedness, response and recovery. Then, with this specific information, a researcher could conduct information gathering with those specific ESF entities (e.g. firefighting, information and planning, etc.) to develop a focused understanding of the use of geospatial information and technologies.

Field researchers have an obligation to expert participants to establish a detailed offsite bootstrapping campaign to develop baseline knowledge of the work domain. In the second part of this chapter, detailed information about hurricanes and hurricane hazards resulting from bootstrapping was presented. This review emphasizes the development of a broad understanding of the hazard being studied that includes the physical characteristics, the political and economic aspects, the social issues and emphasizes the study of information technologies and tools as an independent dimension of the hazards research framework proposed by Tobin and Montz (1997). The completion of an online FEMA training course about hurricane management contributed to the development of baseline knowledge. The course highlighted the stages of emergency management decision making during hurricanes and presented technologies other than GIS (e.g. HURREVAC), that were critical to emergency managers during crises. Through the application of the initial questionnaire coupled with an in-depth study of the history of technologies and GIS in emergencies prior to field work, I was able to develop an informed knowledge base on which
to select appropriate sites for field work and to build a strategy for specific knowledge elicitation exercises for onsite visits.

The initial design for the onsite knowledge elicitation and design activities included: semi-structured video-taped interviews, scenario building exercises, round table discussions and video taped reconstructions of GIS use at their facility. Prior to the offsite analysis, the collaborative levels considered for emergency management primarily included federal, state and local level responders. The nature of collaboration was found to be much more complex, with local cities, organizations, and multi-tiered state and local responders all interacting in disaster response. Moreover, the types of information and the range of situations for which geospatial information was appropriate spanned across multiple hazards and disasters. Furthermore, during informal interviews, several participants indicated that the use of GIS was only recently being recognized as a powerful tool for assisting with mitigation, preparedness, response and recovery operations. They also indicated that every county, state, and federal program used different operating system platforms, possessed different GIS packages, and had varying levels of GIS expertise, with several counties and large portions of states having little or no GIS program in place. This information indicated that there was considerable room for expansion of GIS, and very little if any guidelines on its use and utility in emergency response.

The offsite work helped to uncover the diversity of GIS use among emergency response organizations from federal to local levels. GIS programs across states were highly varied in personnel numbers, training, and technology use. Each division had unique methods for distributing geospatial information to the decision makers in times of critical situations. The information collected in this chapter, taken collectively was used to select the locations for onsite visits discussed in the following Chapter V: Stage II: Onsite Cognitive Task Analysis.
Chapter V:
STAGE II: On Site Cognitive Task Analysis

“Could a greater miracle take place than for us to look through each other’s eyes for an instant?”

-- Thoreau --
5.1 Introduction

Upon completion and examination of the results of the preliminary offsite work, the CTA research transformed into preparations for onsite knowledge elicitation sessions with domain experts. As detailed in Chapter IV, questionnaire results and bootstrapping prompted the selection of hurricanes as the focus of the onsite visits. Informal phone discussions and web searches narrowed the search to the Florida State Emergency Response Team (SERT). The Florida SERT was widely recognized for their advances in geospatial information technologies and their role in hazard and emergency response for all disasters, with hurricanes filling a special niche. The SERT team has a mapping division within the Information and Planning group, housing four full time GIS professionals. The Emergency Operation Center in Tallahassee Florida was targeted as the primary site for knowledge elicitation exercises. The EOC was built to withstand over 300 mph winds, outfitted with large screen displays, conference rooms, and state of the art technologies. The building also contained a power generator to maintain operations in the event of total power failure, thus advanced technologies would continue to operate during the immediate response and recovery activities. The SERT team also had several mobile command posts that could be deployed in advance of an approaching hurricane for rapid response and recovery. Experts in this advanced facility could provide information related to command and control activities, the role of maps, mapping technologies, and collaborative emergency management.

To triangulate the information, a multiple sites in another state were selected. The South Carolina Emergency Management Division (EMD) had recently been relocated to a brand new, state of the art Emergency Operations Center in the National Guard Armory in Columbia, South Carolina. The EOC layout was modeled on Florida SERT’s EOC. This EOC had specialized collaborative workspaces for Emergency Support Functions (ESFs) lining the EOC command center, an expanding computing hardware and software program, and multiple, large screen displays for collaborative decision making. The division had maintained an active partnership with hazard researchers at the University of South Carolina’s Hazard Center under the direction of Dr. Susan Cutter and was receptive to continuing research opportunities. The division used maps to inform decisions, but GIS was a relatively new addition to the South Carolina EMD’s activities and had been identified as an area for continued development and expansion. The SC EMD agreed to join the study, adding a new dimension to the study’s pool of participants.

Geographers have long studied the impact of scale in research activities. Scale was considered an important component for this research project. Thus, an effort was made to include county as well as state agencies in the field work. Contacts in Tallahassee and South Carolina
provided a list of coastal counties with active GIS programs that might be willing to participate in the research.

The knowledge elicitation sessions were scheduled over a one month period in the two participating states. In South Carolina, the State level EMD was scheduled as the first stop. The Hurricane Program Director and the GIS analyst committed to multiple day participation for 2-4 hours each. Referrals to Horry and Charleston Counties yielded shorter, 1-2 hour scheduled interviews with the county Public Security Directors in charge of their county’s EOCs. These county EOCs represented the next two onsite visit sites following the state level sessions.

Finally, the Florida State Emergency Response Team committed to a week of participation with anywhere from 6-12 participants depending upon individual availability. Potential participants for the research effort included the division director, the state’s EOC director, the Information and Planning Chief, the Operations Manager, the Hurricane Program Manger, the GIS director and a staff of GIS analysts.

5.2 Goals and Planned Activities for Onsite Work

Field researchers must be flexible. To prepare for potential schedule changes and other emerging constraints, the goal of the study (understanding work with geospatial information during hurricane response) served as the high level focus for all sessions. If emerging constraints prevented the application of a specific technique (such as concept mapping), my fall-back strategy was to proceed with 1) semi-structured interviews with critical incident probes 2) facilities tours with an emphasis on identifying the stages of hurricane response activities for that particular organization and to obtain testimonial accounts of the use of maps and mapping technologies during past hurricane events. These two elements, stages of response and recollection of past events, were the crucial ingredients needed to meet the need to create and design simple scenarios of collaborative emergency management during hurricane response in support of the DAVE_G project.

5.2.1 EOC Tours

At all sites, time was allotted for an EOC Tour on the first day. I wanted to identify the key locations where decision making activities took place and their relationship to GIS and mapping technologies. Specifically, I focused on the placement of meeting rooms, computers, and the presence of large screen displays. For collaborative decision making contexts, attention focused on the amount of space the responders had to work in, the noise level during emergencies, the information and communication sources available (data, phones, televisions, web) and the power supply including backups and generators. This information was collected to
help me understand the difference among working environment at each place, but is not fed into comparative models of building layouts.

5.2.2 Participant Information Forms

A structured participant information form was developed to obtain information about each participant’s background and past experience in emergency management activities.

5.2.3 Semi-Structured Interviews on Hurricane Response

Initial, semi-structured interviews were designed to obtain a general overview of work with geospatial information during emergencies. Specific attention was placed on the identification of Emergency Support Functions that had an extensive mapping requirement. (Recall that ESFs are an organizational unit for coordinating emergency management resources from local, state and federal agencies that complete specific tasks during emergencies). Other questions focused on the role of maps, visual images, databases, software packages, real-time data, and GIS use. Probes for past critical incidents and events were applied during the first semi-structured interviews.

Identifying critical incidents means that I focused on determining, describing and defining the important decision making activities in the crisis management process. Several probes were developed to prompt the recall of past events. These probes were written to help the participant actively recall important historical critical incidents. The questions written below were only created as personal memory aids with the actual question often being shorter and focused on ‘can you recall a time when X or Y occurred.’ The prompts I used as memory aids for the types of past events to discuss are included below.

Questions and probes for critical incidents:

? Can you recall a time in which single or multiple individuals used a map as the center piece to solve an emergency response situation?
? Tell me a story involving a hurricane emergency where breakdowns occurred during the emergency management process because of maps or geographic information?
? Regarding collaborative activities, can you recall a time where communications broke down during hurricane management?
? During past collaborative emergency situations, can you describe how maps are obtained during hurricane response?
? Do you recall a time that real time information was needed or used?
? Given that situation, what format were the maps in (were they shown onscreen or as paper products)?
? Can you recall a specific instance where a decision maker asked the GIS analyst for a map? What did they ask for?
? Can you recall a time where multiple people interacted via a map on a wall or large screen displays?
5.2.4 Mission Scenario Selection and Refinement

For each state, the identification of a single mission scenario that would structure procedural concept mapping exercises (discussed below) was a priority. During initial semi-structured interviews with the site liaison, a primary goal was to discuss hypothetical emergency scenarios or past training exercises that could be used as mission scenarios. The goal was to have a generic mission scenario for procedural concept mapping sessions. During these sessions, each participant would discuss their work activities for a specific time and situation, allowing comparisons across team members. For both South Carolina and Florida, I wanted to obtain printed handouts of the temporal stages of response, maps depicting a storm’s location, or a series of steps that could serve as prompts for procedural concept mapping with the other participants.

5.2.5 Procedural Concept Mapping – individual and group

Concept maps are a knowledge elicitation technique with high flexibility for adaptive situations. For this research on hurricane emergency response, the temporal component of hurricanes prompted the inclusion of timelines in all concept maps. Thus, the concept maps are procedural concept maps, with a starting and ending point for the knowledge elicitation session. Because all KE sessions were held onsite, I did not have advanced knowledge of the availability and presence of white boards of adequate and consistent size for procedural concept mapping. Thus, another format for capturing the concept maps was devised. To maintain consistency across all sessions, large rolls of white paper were used as the medium for constructing concept maps. As a variation to traditional concept mapping methods, I used colored Post-It™ notes to label concepts and colored markers to depict the linkages. The Post-It™ notes allowed flexibility (while more rigid than a white board, they could be moved and restructured in real time as needed). Colored markers were used to help distinguish between temporal stages of the mission scenario (e.g. planning, response, recovery, etc).

Time lines anchored the concept map and the mission scenario specified the specific real world time span to be discussed in the sessions. The center line (see figure 5.1) represents both time and the interviewee (e.g. EOC Manager). Any work he or she does is represented by an arrow off of that center line. Temporal events (represented as concept nodes) with specific timing would be placed ON the time line. The goal of the timeline was not to identify specific times (i.e. 2:00pm EDT), but to uncover the order of actions, activities, decisions, and information flow. As
a further variant in concept mapping, group sessions were planned in which two participants
would identify the key nodes between their two maps, helping to produce a simplified, summary
map of the critical nodes and their relationships necessary for team work, group cognition, and
collaboration.

5.2.6 Exit Questionnaires

A set of exit questionnaires was developed to meet two goals. First, they were developed
to obtain feedback about the time commitment, perceived utility of specific techniques,
scheduling issues, and overall experience of the KE techniques used in the onsite Cognitive Task
Analysis. This information was important to adaptively refine the process for future, related field
work. A second was to obtain opinions about how advanced, multimodal technologies such as a
gesture-speech powered map might augment emergency management decision making and to
judge whether or not such technology was perceived as a useful technology to the emergency
managers. This information was important to inform the conceptual design of a gesture speech
enabled GIS. The remainder of the chapter focuses on a detailed reporting of the onsite fieldwork
activities and specific information collected during this stage of the Cognitive Task Analysis.

5.3 Overview of the Field Work in the Cognitive Task Analysis

CTA (described in Chapter II) is an iterative, ethnographic approach to understanding
work in context. Analysis within CTA is a process for development of an understanding of
specific parts of a system, that when taken collectively, help improve understanding of the larger
context within which subcomponents are situated. This approach focuses first on understanding
the sub components of the system (hurricane response) and how that component fits within the
larger work domain (emergency management). My approach (discussed in Chapter III) to
analyzing the domain of emergency management involved separation of the information
collection into offsite work, onsite work, and modeling and design. Moreover, I studied specific
agencies from the federal to the county level. At each level, I worked on building an
understanding of the social organizational elements of the emergency management divisions, the
specific decision making activities, the information requirements for the domain, and the
problems that the experts encounter in their specific duties.

Taken collectively, the analysis is a combination of the entire process of preliminary
work, field work, model creation, and envisioned scenarios. The following sub-sections provide
detailed accounts of one portion of that analysis, the onsite field research. My analysis of the
information collected is presented as a detailed account of the activities that were used to elicit
knowledge along with the knowledge that was acquired. I analyzed all of the information that I
collected during the field work, and present the information as it relates to improving and
building a holistic understanding of emergency management decision making with specific attention paid to the role of geospatial information and technologies during hurricane response.

Video was a primary data collection method used during the fieldwork. All video tape collected during the onsite visits was transcribed into text documents that I used to review the information that was collected and provide an analysis and overview of the salient elements of work with geospatial information in emergency management. The process involved over 70 hours of work at field study sites. Video tape was used to preserve the interview information. Over 16 hours of interviews were transcribed into text (total 116,878 words, 251 single spaced pages). I analyzed the transcripts, as well as other artifact information collected during the field work (documents, datasets, maps, etc). My interpretation of work in hurricane emergency response centers is presented in the following account of the onsite work based on the onsite interviews. Further analysis is presented in the form of models of work in Chapter 6 (in the form of procedural concept maps, summaries of the content, and summaries across all concept maps). The information collected over the course of this Cognitive Task Analysis was also analyzed and translated into abstraction hierarchies and decision ladders, and bulleted lists of the salient decision making activities I uncovered during field work activities with emergency managers. Elements from all of these individual analyses were collectively combined into envisioned scenarios of emergency response work (presented in Chapter 7) that were used by an interdisciplinary design team to develop advanced interfaces to geospatial information technologies.

5.3.1 Original Plan for the CTA

Prior to conducting any field work, concept mapping sessions were conducted with two colleagues as training for field work sessions. Because specific techniques tap specific kinds of knowledge (the differential access hypothesis (Hoffman et al. 1995)), I chose several traditional knowledge elicitation methods (questionnaires, probes for critical incidents, semi-structured interviews, concept mapping). Extensions to traditional concept mapping, as noted above, included the use of the centerline as the interviewee, the use of colored Post-Its™ and markers to support both categorization of activities and entities through easy revision as the concept map evolved, and that the sessions would be conducted on table tops (instead of wall boards). The overall plan was to develop and employ a strategy in South Carolina and depending upon the success or failure of specific techniques and the overall procedure, to adaptively adjust the exercises with the participants in Florida. Specifics of the plan for each site are detailed below.
5.3.2 Preliminary Plan – South Carolina EMD

The planned structure included 1) Initial Semi-Structured Interviews (Introduction, Participant Information Forms, Questions related to map use, Critical Incident Probes, Mission Scenario Creation, Temporal Timing of Mission Scenarios), 2) Individual Concept Mapping, 3) Two Person Concept Mapping / Group Discussion, 4) Exit Questionnaires. The first day’s activities were scheduled for introductions, an overview, an EOC tour, and the initial interviews (the interview with the liaison focused on mission scenario identification). Concept mapping sessions were scheduled for day 2.

Day 1: Introductions & Initial Interviews
EOC Tour
Duration: 1 HOUR, (two one hour sessions)

Day 2: Individual / Group Concept Mapping
Morning: Individual concept mapping.
Duration: 1 hour (2 one hour individual sessions)
Break: (~2 hours)
Afternoon: Two-Person Concept Mapping, Validation, & Exit Questionnaires
Duration: 1-1.5 HOUR (one, 1-1.5 hour group session)

5.3.3 Preliminary Plan - Horry and Charleston Counties

Two Counties were chosen to help validate information collected at the state level and national levels. I assumed counties would provide new and potentially different information, helping to develop a broader view of collaborative crisis management. Public Safety Directors for Horry and Charleston county South Carolina agreed to participate in short, 1-2 hour meetings with the possibility for further participation to be determined on site. Because of the shortened time frame within which to work, the county level interviews were designed to match the initial interviews with state level liaisons in some respects, but without the focus on mission scenario creation and instead shifting focus to probes of past critical incidents and the collaborative interaction between state and county level responders.

5.3.4 Preliminary Plan - Florida State Emergency Response Team

Other than the increase in number of days, the plan for the Florida sessions was the same as for South Carolina, with adjustments based on the lessons learned in South Carolina and the availability of the participants.

Day 1 & 2: Introductions & Initial Interviews with liaison and GIS director
EOC Tour
Duration: 1 HOUR, (eight one hour sessions)

Day 3 & 4: Individual Concept Mapping
Duration: 1 HOUR (eight one hour sessions)
Day 4 & 5: Two Person Concept Mapping.
Duration: 1 HOUR (four one hour sessions)
Day 5 or 6: Whole Group Concept Mapping
Duration: 1-1.5 hours (one 1-1.5 hour session)

5.4 Instantiating the CTA: South Carolina Emergency Management Division

5.4.1 Introduction

All activities were coordinated through the site liaison. This person served as the contact for all communication prior to arriving on site, helping with recruitment and scheduling of other participants for team based knowledge elicitation and working to develop the mission scenario that would guide concept mapping sessions. Upon arrival at the facility in Columbia, South Carolina, the liaison conducted introductions with several members of the division staff (non-participants) and then convened an introductory meeting in a conference room. The liaison (Hurricane Program Manager) and the second participant (GIS Analyst) were present and were provided with handouts of the goals of the larger DAVE_G project of which this work was contributing. The handout also contained the example scenario of the PI’s envisioned system presented in Figure 1.1.

The SC participants were shown a brief series PowerPoint slides about the types of research being conducted at the GeoVISTA Center, followed by a discussion of the envisioned scenario and finally, a working video clip of an early DAVE_G prototype system. At the time, the DAVE_G system supported zoom, pan, display of road and county layers based, in part, on the information collected in Stage I. Next, the participants were given an overview of the types of knowledge elicitation activities in which they would be participating. After I answered any questions they had, the remainder of the sessions were scheduled, and the liaison proceeded with the tour of the EOC and division facility.

5.4.2 EOC Tour and Division Facility

During the tour, I videotaped the EOCs layout – noting computer placement, large screen displays, workspace conditions, conference and planning room locations and size, sources available including data, phones, television feeds, web access, the electrical supply, power back ups, etc. I was also given paper handouts of the EMDs organizational structure, hurricane plan, and OPCON classification.

The South Carolina Emergency Management Division’s website (http://www.state.sc.us/emd/) indicates that the agency has 75 employees in 7 divisions. Their distribution includes: Director’s Office (2); Public Information (2); Preparedness and Response (34); Recovery and Mitigation (12); Critical Incident Management Group (CIMG) (4); Administrative Services (5); and Operations Support (6).
The division (Figure 5.2) is located in Columbia, South Carolina at the National Guard Armory. The EOC contains stations for the management staff and individual county warning points. A county warning point is a communications liaison for dissemination of information between City/County Governments and emergency agencies. Behind the management staff and county warning point liaisons are three large screen displays for information sharing among all persons actively working in the EOC (Figure 5.3). Along each side of the EOC are small conference rooms dedicated to Emergency Support Functions (ESFs). Personnel from state and local agencies collaboratively work together in support of the missions for each Emergency Support Function (ESF) (Figure 5.4). At the back of the EOC is a special Governor’s Briefing room where the majority of the critical decisions related to protecting the state during emergencies are made. This room contains a long conference table and two flat screen LCD panels at either end of the table; the panels are mounted on the ceiling. Individual workstations on the EOC floor are reserved for county liaisons. The EOC is equipped with tables, computers, and collaborative workspaces for the numerous responding agencies and personnel.
After the conclusion of the tour, the semi-structured interviews were conducted. Those interviews were structured as follows: 1) Obtain informed consent, 2) Distribute participant information forms, 3) Conduct semi-structured interviews (ESF Prioritization; maps and visual image use; database information gathering; role of real time data and information; use of GIS), 4) Probe for critical incidents and decisions, 5) Mission scenario selection and refinement (conducted only with liaison) and determination of temporal structure.

5.4.3 Participant Information

The Hurricane Program Manager is based in the Preparedness and Response division and the GIS Analyst works in Operations Support. Their background and experience collected on the

<table>
<thead>
<tr>
<th>Individual Background &amp; Experience</th>
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</thead>
<tbody>
<tr>
<td><strong>Division</strong></td>
</tr>
<tr>
<td><strong>Title</strong></td>
</tr>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>Emergency Management Training</strong></td>
</tr>
<tr>
<td><strong>Years in Emer Mgmt</strong></td>
</tr>
<tr>
<td><strong>Years of GIS Experience</strong></td>
</tr>
<tr>
<td><strong>Years in EOC</strong></td>
</tr>
<tr>
<td><strong>Number of times present during EOC activation</strong></td>
</tr>
<tr>
<td><strong>Types of Emergencies</strong></td>
</tr>
<tr>
<td><strong>Hurricanes</strong></td>
</tr>
<tr>
<td><strong>Expertise Rating 1= novice; 10 = expert</strong></td>
</tr>
<tr>
<td>Emergency Management</td>
</tr>
<tr>
<td>Hurricane Response</td>
</tr>
<tr>
<td>GIS</td>
</tr>
</tbody>
</table>

Table 5.1: South Carolina Participant Information Summary
participant information forms is included in Table 5.1 (DNR means they did not respond).

### 5.4.4 Semi-structured Interviews

Both participants were given appropriate Informed Consent documentation and a description of the process while the video camera was set up for the initial interview in each participant’s office. The sessions focused on the activities and the role that maps, geospatial information technologies, and other tools have in supporting their work activities during hurricane preparedness and response. Specific sub themes are discussed below.

#### 5.4.4.1 ESF discussions

During semi-structured interviews, one focus was on the role of ESFs during preparedness and response activities. The Hurricane Manager in SC indicated that the most important aspect of emergency management was ensuring the health and safety of the citizens. He pointed out that ESF designations vary from state to state. While the designations are based on FEMA regulations, individual states have created their own ESF categories depending on specific needs. For South Carolina, a special ESF (ESF-16, Evacuation and Traffic Management) was created after Hurricane Floyd. ESF-16 is responsible for planning, monitoring and managing the execution of evacuations. Activities included coordinating the management of over 460 key intersections (traffic control points) along evacuation routes that were manned by law enforcement personnel during coastal evacuations. They handled planning and support for highway reversals and counter flow plans. The next ESF identified as important during hurricane response was ESF – 6 Mass Care. Workers in Mass Care manage and monitor over 300 shelters in South Carolina. Their work includes mobilization of shelter management staffs, evacuation processing and monitoring of shelter capacities (number of people and duration of stay). These issues are reported to the EOC in case the EOC needs to assist with reallocation of evacuees or resource supply (the GIS Analyst indicated that open and closed shelters was a GIS layer he maintained). ESF-1, Transportation was indicated as a third high priority function. ESF-1 focuses on coordinating movements and evacuations of large contingent populations in the state (such as the Marine recruits on the Paris Island Marine Corps Base or prisoners). In addition to the ESFs mentioned above, 5 additional ESFs are particularly important in Hurricane response: ESF 8 – Health and Medical Services – responsible for individual county’s special needs populations and provision of supplementary oxygen and ventilators; ESF-5, Information and Planning – activates upon threat identification and produces daily situation reports, manages websites and the information management system while assisting the public information officer with media relations; ESF-13, Law Enforcement and Security; ESF-15, Military Support and ESF-2, Communications - provide evacuation assistance.
The GIS analyst indicated that his work required him to make maps for all of the ESFs depending on their immediate needs; however he identified ESF-1, Transportation as a high priority support function. As an example, he cited a recent flooding exercise in which the decision makers provided a list of the roads that were closed and needed to see a map of those roads. After querying the GIS based on road names, the analyst selected all of the individual road segments, created a new shapefile, and printed out the map depicting road closures.

5.4.4.2 Maps and Mapping Technology

No single mapping program is serving the needs of emergency management decision makers. Instead, they are pulling pieces of information from multiple software products and displaying them as needed in the context of emergency management decision making. During hurricane events, the large screen displays in the SC EOC are each dedicated to HURREVAC map outputs, GIS displays, news and/or weather forecasts (See Figure 5.5 below).

Figure 5.5: Two screens in the SC EOC displaying GIS (left) and HURREVAC (right)

The Hurricane Program Manager’s mapping needs are served almost solely by a Hurricane Evacuation support tool called HURREVAC (http://www.hurrevac.com/). HURREVAC is limited use, government funded software available only to emergency managers
and distributed by Sea Island Software, Inc. The software integrates hurricane evacuation information (county clearance times) into a map based decision support tool. Besides evacuation study information, wind speed forecasts and rainfall forecasts are also accessible in the program. The program is used early in hurricane preparation to view storms in the entire Atlantic basin. As the storm nears, the program is used to zoom in on the projected track. It also contains data about the storm’s speed, strength and location for a given point in time and projects its location in the future based on the current National Hurricane Center advisory.

Another program, HURRETRAC, is also used to display information about approaching storms. HURRETRAC is proprietary software developed by PC Weather Products. The participant indicated that HURRETRAC is used to depict the 14 different meteorological storm track models. After zooming into the necessary level of detail, the projected storm track is depicted, along with the statistical likelihood that the storm will impact at a given point on the coast. Specific statistics such as the storm’s forward speed, wind speed, and the time of day are also displayed.

Several other geospatial information products are also used to assist the decision making activities in South Carolina. Detailed Sea, Lake, and Overland Surges from Hurricanes (SLOSH) maps showing the surge zones for South Carolina were created by the Army Corps of Engineers and are displayed onscreen in Acrobat Reader and distributed via CDs to the division. SLOSH models display the potential maximum surge for specific coastal locations (considering both meteorological information and terrain). The latest NHC determination of the SLOSH model’s associated MEOW (Maximum Envelope of Water) is important for decision making activities. The MEOW is based on historical data combined with current information of a storm’s direction of approach, forward speed, and intensity. Other important geospatial information includes detailed regional and national weather maps, satellite weather data, wave heights from offshore buoys and other products from the NWS and NOAA as needed. All of these mapping products are collectively considered and combined into the manager’s situational assessment of the storm and the subsequent recommendations for protective actions.

5.4.4.3 Collaborative Decision Making

The Hurricane Program Manager recalled some past events when division planners collaboratively used maps to make decisions. However, since assuming his current position, South Carolina had not been seriously threatened by a hurricane event. When a storm threatens the state, the decision makers collaboratively discuss information content on printed maps from HURREVAC, HURRETRAK, and water vapor imagery and hold collaborative planning sessions with the threatened coastal counties.
Decisions and recommendations are made during briefings. For example, the hurricane manager advises the director and the governor on the expected forecast and recommends the evacuation type, sheltering needs, and evacuation timing based on the assessment. Depending on how close the storm is, typically 4-5 people are present in either the Governor’s conference room or the EOC director’s conference room (the Governor, when not onsite is patched in via conference call). During these sessions, printed (color or black and white) 8.5 x 11 HURREVAC outputs (and other weather related maps as deemed necessary) are distributed to the decision makers. While large format maps, or large screen projected maps have not been used for the decision making to date, the participant noted, “I can absolutely see occasions where {large maps would be useful} particularly in evacuation decisions.”

During the session, the manager used a large printed map of regional storm surge flood zones to indicate what types of information the decision makers would need (see Figure 5.6 at right). In this figure, the red lines indicate the general movement of the pen he used to indicate the features on the map. Specifically, the participant indicated that groups of decision makers would huddle around paper maps such as this one or onscreen displays to determine what the inundation areas would be for the category of storm (top image). Based on that information, they would focus on individual cities (second image) that had to be evacuated as well as what evacuation routes to use (third image). These small groups of decision makers would also discuss protective actions such as evacuation adjustments and planning for inland areas that were prone to secondary flooding from rainfall (indicated in the bottom image). Based on the results of these meetings, the decision makers issue
recommendations to the Governor, who issues the decisions. Of these decisions, the decision to evacuate is generally the primary focus of the discussions. Specific issues related to making that decision are detailed below.

An important factor in issuing an evacuation order is the evacuation clearance time for individual counties. The evacuation clearance time is the difference between when the first car begins the evacuation and the last car leaves the evacuation network. Evacuation clearance times influence the time when an evacuation decision must be made.

To assist in making this decision, emergency managers use a decision arc. A decision arc (see Figure 5.7) is a circle that is drawn around the estimated location of landfall for a storm. The diameter of the decision arc depends on factors such as individual county evacuation clearance times, the storm’s forward speed, the tourist population, and the type of evacuation. In order for the evacuation to be completed before the hurricane’s tropical storm force winds make landfall, the evacuation must begin when the storm’s gale force winds (indicated by the BLUE circle on the figure) intersect the decision arc as in the diagram below. The intersection indicates the point in time that the evacuation order must be given so that all traffic can clear the roadways before the tropical storm force winds hit the coast. Decision makers can also determine the decision arc manually in the event of computer malfunctions.
While decision makers use tools such as HURREVAC to help them with their decisions, the participant recalled a situation where technology was not available to support the collaborative activities of the state and county responders. During Hurricane Floyd, Horry County was going to have a serious problem with secondary river flooding (resulting from rainfall in North Carolina). At the time, the state and county decision makers had an immediate need to answer the question ‘how high is this river going to go?’ and when it does get that high, ‘where does the water go?’ Unfortunately, at that time, there was no flood modeling technology to provide answers to those questions. They had to rely on their past experience, local knowledge and instinct to decide when and where to initiate sandbagging and evacuations.
5.4.4.4 Evacuation Decision Timeline

The manager was also able to provide detailed procedural knowledge about the decision to evacuate. The South Carolina hurricane plan (updated annually and available at http://www.scemd.org/) contains a list of the detailed events and decision making activities in relation to the timing of the hurricane. Detailed information related to individual decision makers and the specific duties and activities of Emergency Support Functions are outlined in the plan. A general overview of the primary decision making activities for the entire division related to hurricane evacuations and preparations appears in Table 5.2.
## Evacuation Decision Time Line

<table>
<thead>
<tr>
<th>Time Prior to Public Notification of a Mandatory Evacuation</th>
<th>Operational Key Event, Decision Point, or Timing Window (timings are situation dependent)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPCON 5</strong></td>
<td>All Atlantic tropical depressions and named storms are monitored from June 1st to November 30th for potential threat to SC. Track National Hurricane Center’s (NHC’s) tropical cyclone forecasts utilizing hurricane tracking tools. Update each forecast (every six hours) thereafter until threat to South Carolina is over.</td>
</tr>
<tr>
<td><strong>OPCON 4</strong></td>
<td>Assess storm forecast and potential state/regional impact using hurricane tracking tools. Brief Governor and staff after receipt of advisories, as required. Conduct coastal county conference calls to discuss advisories, Governor’s guidance and future actions. Initiate OPCON 4 activities. Enhance public awareness campaign. Notify ESFs and State agencies to initiate ESF SOP activities.</td>
</tr>
</tbody>
</table>

- **96 hours**
  - SCDOT notifies districts and reviews schedules and agreements.
  - Assess storm forecast and potential state/regional impact using hurricane tracking tools.
  - Brief Governor and staff after receipt of advisories, as required.
  - Conduct coastal county conference calls, as scheduled, to discuss advisories, Governor’s guidance and future actions.
  - Issue National Guard warning order for state activation.
  - DPS issues warning order to SC Highway Patrol.

- **72 hours**
  - Assess storm forecast and potential state/regional impact using hurricane tracking tools.
  - Brief Governor and staff after receipt of advisories, as required.
  - Conduct coastal county conference calls, as scheduled, to discuss advisories, Governor’s guidance and future actions.
  - Notify SCDOT to contact portable toilet and bottled water vendors to support set up of comfort stations.
  - Notify SCDOT to preposition highway advisory radios.
  - Instruct Communications (ESF-2) to issue pre-planned radio/cell phone equipment in support of Evacuation Traffic Management (ESF-16) activities.
**OPCON 3**

- **36 hours**
  - Evacuation Traffic Management ESF (ESF 16) mobilizes.
  - Assess storm forecast and potential state/regional impact using hurricane tracking tools.
  - Brief Governor and staff after receipt of advisories, as required.
  - Continue coastal county conference calls, as scheduled, to discuss advisories, Governor’s guidance, evacuation decisions and future actions.
  - Initiate OPCON 3 activities.
  - Recommend Governor issue a State of Emergency.
  - Issue Governor’s Executive Order for National Guard state active duty and state EOP activation.
  - Call National Guard to state duty to support evacuations.
  - Intensify public information campaign.
  - Increase SEOC activation to Limited Activation or above.
  - Discuss region traffic coordination procedures and evacuation timing with FEMA and Atlantic coast states’ FOCs.

**OPCON 2**

- **25 hours**
  - Notify SCDOT to deploy resources (bottled water and porta-pots) for comfort stations.

- **24 hours**
  - Assess storm forecast and potential state/regional impact using hurricane tracking tools.
  - Brief Governor and staff after receipt of advisories, as required.
  - Evaluate lane reversal criteria regarding reversal actions.
  - Continue coastal county conference calls to discuss advisories, Governor’s guidance, evacuation decisions and future actions.
  - Initiate OPCON 2 activities.
  - Increase SEOC activation to Full Activation.
  - Deploy Law Enforcement (ESF-13) security resources to staging areas.

- **20 hours**
  - Notify ESF-16 to move traffic evacuation and lane reversal resources to forward staging areas.
  - Notify counties to prepare to staff Traffic Control Points (TCPs).
  - Notify Public Information Phone System (PIPS) support agencies to prepare for activation.
<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPCON 1</strong></td>
<td></td>
</tr>
</tbody>
</table>
| - 13 hours | - Assess storm forecast and potential state/regional impact using hurricane tracking tools.  
- Brief Governor and staff after receipt of advisories, as required.  
- Governor's decision made regarding voluntary evacuation.  
- Advise coastal counties of Governor's voluntary evacuation decisions.  
- Notify counties, as determined by ESF-16, to staff TCPs.  
- Notify ESF-5 to execute voluntary evacuation shelter plan.  
- Initiate OPCON 1 activities.  
- Focus public information campaign specifically on evacuation information.  
- SEOC continues at Full Activation. |
| - 12 hours | - Governor's public notification of Voluntary Evacuation.  
- Activate PIPS and announce telephone number.  
- Broadcast EAS message.  
- Issue news releases delineating vulnerable areas.  
- Continue entering NHC's hurricane forecast into HURREVAC and other hurricane tracking software.  
- Brief Governor and staff after receipt of advisories, as required.  
- Monitor impact of voluntary evacuation.  
- Zero hour for ESF-16 evacuation preparation. |
| - 9 hours after public notification of voluntary evacuation or 4 hours after notifying ESF-6. | - Voluntary Evacuation shelters open. |
| - 3 hours | - Governor's decision made to order a Mandatory Evacuation.  
- Notify ESF-6 to execute mandatory shelter plan. For a strong Category 2 or higher storm, also execute reserve shelter plan.  
- Initiate Lane Reversal Clearance (if lane reversal ordered). |
| - 0 hour | - Governor's public notification of Mandatory Evacuation.  
- Broadcast EAS message.  
- Issue news releases delineating evacuation areas. |

**Evacuation Monitoring**

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 1 hour after public notification of mandatory evacuation or 4 hours after notifying ESF-6.</td>
<td>- Mandatory Evacuation shelters open.</td>
</tr>
</tbody>
</table>
| Category 1 and 2 storms (lane reversal not initially implemented) | - ESF-16 monitors evacuation status and reports traffic flow (speed & counts, accidents, critical intersections).  
- Initiate lane reversal, if required. |
| For each storm | - Evacuation status monitoring/reporting of  
  - Shelters status  
  - Media activities  
  - Traffic situation. |

Table 5.2: South Carolina Evacuation Decision Timeline (SCHP, 2001)
The Hurricane Program Manager stressed the importance of completing evacuations before the onset of tropical storm force winds. This was a common goal amongst all hurricane prone states, regardless of the state’s specific response strategies. One rule of thumb he identified for managing evacuations is that decision makers try to issue a voluntary evacuation at least 9-12 hours before mandatory evacuations so that the voluntary evacuation has a significant effect. Directly related to the evacuation decision timeline is the estimated arrival of tropical storm force winds which has a direct impact on evacuation clearance times. Clearance times vary by location of impact, population, and size of the storm. A further issue confounding the declaration of an evacuation is the time of the day. Generally, emergency managers try to time the evacuation order with regular news broadcasts in the morning, afternoon and evening, so that the message reaches the widest audience.

5.4.5 Mission scenario selection and refinement

The Hurricane Program Manager helped with the identification of a mission scenario for use in concept mapping sessions. The hypothetical storm, Hurricane Bertha, was based on an actual storm, Hurricane Fran. In 1996, Category 3 Hurricane Fran posed a direct threat to the South Carolina coast, requiring evacuations and mobilization of the EOC. The storm turned north, and eventually made landfall in North Carolina, despite the early indications of landfall directly in South Carolina. The hypothetical storm that was selected for mission scenarios did not turn, but followed the initial track. The storm was a category 3 hurricane (115 mph winds) moving west-north west at 10 mph with the forecast track passing directly over Columbia, SC and the strongest quadrant affecting Horry County and eye wall landfall on Charleston, South Carolina (the two coastal counties scheduled for onsite visits).
Figure 5.8  HURREVAC  Outputs from Hurricane Fran
5.4.6 Temporal structuring of the mission scenario

The mission scenarios had to have the same temporal structure for all participants so that those temporal events could be lined up for comparative purposes. It was also important that each participant received the same initial prompt, mid-interview prompts, and ending prompt for the procedural concept maps. Event sequence and timing for the scenario was determined by using the South Carolina evacuation decision timeline from the statewide hurricane plan.

The mission scenarios comprised five sections that matched the five OPCON (Operating Condition) levels for the state EOC. The OPCON levels provided not just timing elements, but also information about the tasks, critical junctions and decision requirements. At OPCON 4, the hypothetical scenario based on Hurricane Fran was introduced. Table 5.2 below shows the specific OPCON levels used as temporal prompts for the procedural concept mapping sessions. For example, the first prompt was OPCON 5 with no storm. The second was the introduction of Hurricane Fran, a Category 3 storm tracking on Columbia (which automatically prompted a transition to OPCON 4). The prompts continued similarly for each stage, with the storm staying on track, and the participants discussing activities at each OPCON level. In the table, the negative number in front of the hour’s designation (e.g. -96; -25) indicates the amount of time before the storm would make landfall based on the most current National Hurricane Center advisory. Discussion focused on the role of maps, collaboration, and decision making activities during each of the OPCON levels. In Table 5.2, the details of the OPCON levels are presented in further detail.
OPCON 5: Hurricane Season (June 1st – November 30th)

This OPCON indicates that the SEOC is at normal day-to-day operations. Prior to hurricane season, all hurricane plans will be reviewed and points of contact/telephone numbers verified. During hurricane season, all storms are tracked and monitored at this level.

OPCON 4: Alert (-96 - -48 Hours)

Once it is determined that a storm poses a possible threat to SC, the SEOC and affected County EOCs will move to OPCON 4. The primary events that will occur at this level are the notification of key personnel of the hazard, and initiation of preparatory activities. EOCs will be under “Partial Activation,” primarily staffed by emergency management personnel.

OPCON 3: Stand-By (-36 Hours)

Once public officials have sufficient information that a storm poses a significant threat to SC, the SEOC and affected County EOCs will move to OPCON 3. This decision will be based on each individual storm’s characteristics. EOCs will be under “Limited Activation,” staffed by emergency management personnel and key support agencies. The primary events that will occur in this stage include evacuation discussions (including voluntary evacuation and mandatory evacuation), holding pre-evacuation conferences and other preparatory activities.

OPCON 2: Preparation (-25 Hours)

Once a state-level decision is made that a voluntary evacuation or mandatory evacuation order is imminent, the level automatically moves to OPCON 2. EOCs will be under "Full Activation" at this level.

OPCON 1: Evacuation (-13 Hours)

Once a voluntary evacuation recommendation or mandatory evacuation order is announced to the public, the level automatically moves to OPCON 1. At this level, the SEOC and County EOCs will coordinate the evacuation. EOCs will remain at OPCON 1 through storm landfall, reentry and into the response phase.

Table 5.2 South Carolina OPCON Classifications:
(Source: South Carolina Hurricane Plan: Basic Plan (June 2001): pgs 10-11)

5.4.7 Procedural Concept Mapping

The second day in Columbia consisted of procedural concept mapping with the Hurricane Program Manager and the GIS Analyst. Following those sessions, both participants were brought back for a final group concept mapping session. In South Carolina, concept mapping was conducted on large tables inside the EOC. At the start of each concept mapping session, participants read a set of instructions and then were given a brief demonstration of
concept map production for a winter storm emergency. Participants were given an opportunity to ask questions, then the video camera was switched on and the concept mapping session began.

Both sessions began with a brief description of the mission scenario. Then, concept mapping sessions proceeded, anchored by the 5 OPCON levels for the state. Prompts for all participants included spoken prompts about past events as well as simple prompts such as, “can you describe that further?” Critical incident prompts and questions were designed to encourage participants to discuss their work activities at specific times during the mission scenario. Specifically, prompts focused on collaborative events and the role of maps at multiple points in time (e.g. at 48 hours out, when a warning was issued, etc). After the last stage of the mission scenario was complete, the concept maps were validated; the participants were encouraged to review each procedural concept map, add any missing information and to recommend revisions. These large, paper based concept maps were stored for formalized processing, review, analysis, editing and a second expert validation (discussed in Chapter VI).
5.4.8 Group Concept Mapping

A two hour break was scheduled between the end of the final individual concept mapping session and the beginning of the group session. During this period, I planned to redraw the two concept maps to provide neat, concise versions of both participants’ concept maps merged into a single map. The number of nodes and size of the concept maps made the planned re-drawing impractical.

Figure 5.10: Example of paper based concept map

Figure 5.11: Expert Validating the Concept Map
Instead, the time between sessions was used to edit each concept map for clarity.

The final session was held in the EOC. First, participants were asked to examine each of their concept maps and validate that I had captured the information correctly. Both participants spent a few minutes reviewing their maps, and neither suggested any substantive changes. After individual validation, participants were asked to discuss relationships between their colleague’s concept map and their own map. Specifically, they were prompted to focus on the relationships between the two concept maps such as common nodes, the temporal arrangement of events, key personnel, decisions, etc. When discussing the relationship between the maps, the participants began brainstorming ideas of what GIS maps they wanted displayed in the EOC for the situation posed by Hurricane Bertha.

To facilitate the discussion, the HURREVAC program was loaded with the historical data from Hurricane Fran was displayed on the large screens in the EOC. Given the track of Hurricane Bertha, the Hurricane Program Manager requested detailed GIS information about Horry County. Data requests included surge zones, evacuation routes, and population densities. The participants conducted a brief dialogue to determine the appropriate map scale to prioritize what layers were needed on the display. The GIS analyst left to create the maps requested and the manager continued to discuss the uncertainty within hurricane tracks (in HURREVAC) and the methods that the National Weather Service (NWS) uses to convey the uncertainty through forecast discussions. To relate the information, he demonstrated the map display and animation features of the HURREVAC simulation that was projected on the large screen. He indicated that the Emergency Management Division is very concerned with whether a storm will turn and if so, whether it will follow the new predicted path. Based on the current storm information, the decision to evacuate was the primary focus for the division’s activities, with sub decisions related to areas to evacuate, timing of evacuation, contra lane considerations (highway traffic flow reversals), and deciding between voluntary or mandatory evacuation orders.
During this session, after about 17 minutes, the GIS base maps were pulled up on a second large screen display in the EOC. The analyst returned and described the symbology included on the map, which was zoomed into Horry County. Specific information layers (represented by circles) included: colleges (brown), hospitals (blue), and HAZMAT (yellow). The Hurricane Program Manager pointed at the display (see Figure 5.12) and asked the analyst to remove several layers, move one up in priority and change the symbology, and to zoom in on a specific county. At that point, the manager requested to see the Category 3 surge layer as well as all roads and specifically, the evacuation routes. The analyst left to add the requested information. Ten minutes later, the data were added and the analyst returned. The manager indicated that he had wanted category 3, but had gotten storm surge information for storm categories 1-5. After a discussion of the importance of the category 3 storm surge zone, the manager returned to the focused discussion about the displayed HAZMAT facilities. The HAZMAT layer was beneath the storm surge flood zone, and thus, the analyst had to change the layer priority to improve the map display.
At the time, both participants indicated that the computer was running at about its maximum capability (however new hardware and software had been ordered to improve the computer’s performance). The hardware limitations slowed the display of the information layers and the GIS software was located on a computer in a separate room, requiring the analyst to return multiple times to make sure the information was displayed correctly. The analyst left after a brief discussion about emphasizing the HAZMAT layer using green triangles instead of yellow. While the symbology was being altered, the manager mentioned that HAZMAT would be only one of several critical facilities that various decision makers would request based on their own specific needs and duties. Also important were hospitals, shelters, nursing homes, schools, mobile home parks, response teams, and any number of other combinations important to the requestor and relevant to the required decision. Once the manager was satisfied with the results of the display, the session concluded.

This situation represents an example of how GIS was being used (at the time of my visit in May, 2002) to aid the decision makers in the entire EOC. At the end of the group concept mapping session, each participant was thanked for their participation and asked to complete a brief exit questionnaire. As the sessions concluded, both participants were asked and agreed to participate in further verification of formalized concept maps and scenarios via follow-up online and phone contact.

5.5 Instantiating the CTA: Horry County Emergency Operations Center

The next onsite visit was in Horry County. The meeting took place in Conway South Carolina at the ML Brown Jr Public Safety Building. The EOC director had committed to a one hour meeting. For this session, the goal was to conduct an interview that followed the same format as in Columbia. After initial introductions and a discussion of the project (via hand outs, PowerPoint presentation and demo), the participant indicated a desire to participate for a couple hours in order to do the concept mapping session. He also brought in a GIS specialist, and we proceeded with concept mapping in an onsite conference room. Thus, both participants were given the informed consent documents for interviewing and concept mapping and their Participant Information forms. While reading the instructions and filling out the forms, the materials were laid out for a merged, two person concept mapping activity using the same mission scenario as at the state level. To take advantage of this opportunity, I flexibly adapted the procedural concept mapping session. As described earlier, the center line represents the individual participant and the time line on the procedural concept map. With two participants, the center line could only be a referent for the general time schedule, and the participants were
represented as concept nodes. The information from the participant information forms is summarized in the following table.

<table>
<thead>
<tr>
<th>Individual Background &amp; Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division</td>
</tr>
<tr>
<td>Title</td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Emergency Management Training</td>
</tr>
<tr>
<td>Years in Emer Mgmt</td>
</tr>
<tr>
<td>Years of GIS Experience</td>
</tr>
<tr>
<td>Years in EOC</td>
</tr>
<tr>
<td>Number of times present during EOC activation</td>
</tr>
<tr>
<td>Types of Emergencies</td>
</tr>
<tr>
<td>Hurricanes</td>
</tr>
<tr>
<td>Expertise Rating 1= novice; 10 = expert</td>
</tr>
<tr>
<td>Emergency Management</td>
</tr>
<tr>
<td>Hurricane Response</td>
</tr>
<tr>
<td>GIS</td>
</tr>
</tbody>
</table>

Table 5.3: Horry County Participants

A brief discussion about ESFs was conducted. The director indicated that ESFs not only differed from state to state, but also vary between county and state levels. The director indicated that his priorities were in the ESF for Transportation, and second, Law Enforcement. He pointed out that at the state level, ESF 16 existed for evacuation support, but at the county level, those activities were handled by the law enforcement community. Another important point noted was that the information in the county’s databases (for example, street center line files at 2 foot contour intervals) contained more detail than the coarser, state level information. The director illustrated the issue of scale with the following statement related to where the county level use of GIS was headed that year.

“…on some hurricanes, it’s very possible to have a large rainfall event precede, the arrival of the, quote, hurricane. I’m a flat coastal county; I need to know elevation wise, am I going to flood, here? On a potential evacuation route, if I
receive 11 inches of rain, can I project my low lying areas? That these evacuation routes [gestures to map], that [the flood] might impede my evacuation before the arrival of the storm. We’re not at that point yet, because now it’s, ‘you ever been here?’, ‘well, remember when it flooded outside of the Toyota dealership?’ Those are the only ways we’re doing it now. But when we get to this point, we can start putting some true, GIS analysis on it. So that’s the planning terms that we were talking about.”

The same mission scenario used in Columbia was used for this session. As the hypothetical storm neared, the session progressed through each of the state’s five OPCON (Operating Condition) levels. The general questions (about maps) and critical incident probes from the planned interview were inserted in the discussion where practical. Upon finishing the scenario at OPCON 5, the rest of the probes were discussed. Additionally, the participants related several other, non-hurricane scenarios in which GIS and map use were critical for emergency management at the County Level.

The participants pointed out that in Horry County, SC the Public Safety Director is in charge of hundreds of staff. Among them are GIS specialists, including the second participant. During emergencies, the director makes information requests to this specialist, and the specialist then works with the county level GIS team to meet the information requests and create maps depicting the desired information.

Figure 5.13: Group Concept Mapping in the Planning Room

During emergencies, groups of decision makers often meet in the room in which the concept mapping took place. The room did not contain any large screen electronic displays.
Instead, a large paper map of the county served as a planning aid. The EOC was occupied at the time of the visit, and thus could not be filmed. The room had a large screen at the front of the room with a ceiling mounted projector. During emergencies and public planning meetings, GIS maps were projected onto the large screen display for public viewing.

The director indicated that each change in OPCON level is associated with a narrowing of the scale of decision making activities and a focusing of the scope of operations. The scale narrows as the storm approaches and becomes more focused on the specific point of impact. The process of focusing influences the mapping needs and GIS activities at the county level. To support the process, developments in the county include the expansion of dynamic GIS. As information about damage and hazard related issues are reported via the phone or IRIS (Internet Routed Information System), a database specialist is working behind the scenes to constantly update the information in the database. That information is then displayed on screen for the director. The goal is to avoid the past activities in which the director had to constantly request new updates for a given situation in multiple areas.

“We don’t want to have to be printing a thousand paper maps, we want to do as much dynamically and on the workstation as possible, and then we’ll print maps out for the guys that are going out in the field. But if we hear, you know, power line across the street 501 at this place, we want to put that on a layer or on a shapefile and have it up as soon as possible.”

The director described a situation that had occurred during a flood resulting from Hurricane Floyd.

“Using my map. I’ve got two major east to west routes, highway 501, and highway 9, these are my two major east to west routes. Hurricane Floyd, right here, I had about three foot of water rolling over the bridge, ok? What we did at that point was, we said, we dropped a polygon over this and said, impassible at that polygon, and that’s basically all that they did...A lot of this was on a paper map and we put a big red x over it and said, ‘can’t go there.’ (Figure 5.14)"
The use of GIS expanded significantly in Horry County during Hurricane Floyd. The manager relates the situation below. The base map was created by an ESRI specialist sent in to assist in the response activities. The flood was moving south from North Carolina and had not reached Horry County. A flood stage occurs when the river level has the potential to overflow onto surrounding areas. The probabilities were highest for a flood stage of 13 feet, and a 17 foot flood stage was also possible. The ESRI specialist created a base map and buffered the stream with two polygons, one displayed in orange for the 17 foot flood and one in red for the 13 foot flood. To illustrate the situation during the interview, the director pointed to the map in the room and, using his entire hand, illustrated where the flood was going (Figure 5.15 left image) and then indicated the buffered region by extending two fingers and tracing where the buffer was displayed (Figure 5.15, right image).

![Figure 5.15: Participant using gesture to demonstrate flood zones and buffer layers](image)

The director then instructed his workers to conduct a community assessment to identify all vulnerable churches, schools, nursing homes, hospitals, cemeteries, sewer lift stations, power plants, critical telephone connection sites and neighborhoods. It took the workers a day and half to determine the vulnerable facilities and provide that information to the director. The director said:

“At that point, I prioritized what we were going to protect. And, so based on the GIS technology that had come in, and they had all this, and it was all hand written on this printed out map. I said, obviously, if you were in the red area, you were a higher priority than the orange area. It was a higher probability of a 13 foot flood than a 17 foot flood. So we were able to get that data, identify the community assets that were in those two zones, and what was out of the two
zones which was actually, at least as important as what did I not have to worry about."

The director indicated that among hurricane hazards (surge, wind, tornadoes, etc), the flooding from the hurricane was the biggest worry. “I’m more concerned about flooding. Run from the water, hide from the wind.” Another situation that arose during the flooding from Hurricane Floyd is related below:

“We lost Highway 9, right here, we flooded this whole route, so I lost one of my two major east west routes, and I had one major road here left…Right here, on the south end [of the highway] is [the] Hospital.”

The number one priority was to maintain access to the hospital because had the route been flooded, the county would have been cut in half and the one-way trip to the hospital from the population center via other open routes would have been increased to three hours.

“So my request, to the DOT folks, I said, ‘how high is this road?’ You have no idea the difficulties associated with that statement. That should have been an easier issue, but it was very difficult.”

Learning from that past event, the GIS team obtained SPOT satellite elevation heights that could be merged with the county roads, but at the time, the director had to collaborate with engineers and estimate the required level of sandbagging to protect the route. While the team was successful, the information they needed was not available to help make the decision on where to
sandbag and at what level of flooding to protect the road. The manager related similar situations aimed at preventing bridges from being washed out and maintaining and protecting individual buildings from secondary flooding. In each case, the information was not available and thus, could not be mapped. The GIS team actively collects data based on lessons learned during past emergencies.

During the session, the GIS specialist discussed the directions that GIS technology was moving in his division. This specific example highlights the use of mobile devices connected to a GIS specialist at the command center.

“What I foresee with GIS, mostly is, using some of our existing data, but a lot of it’s going to be creating brand new data. Because we’re going to actually have people in the field saying ‘ok it’s flooded from here to here, and then we’ll create a file.’”

The agency was planning on focusing on damage assessment in order to help the county request and prioritize disaster relief assistance from FEMA, the National Guard, the Salvation Army, etc. The immediate need is to assess the damaged buildings. The GIS division was planning to use handheld GPS with an IPAC, a pocket pc with ArcPad and survey damaged areas in vehicles or helicopters to build polygons of the extent of the damaged area. The polygon would be used to query the building values in the parcel subdivision and determine an estimated dollar value of the damage that the director could use to request funding.

The participants discussed other planned developments in Horry County. Specifically, the opportunity to deploy multiple mapping units in field command posts was considered a primary area of expansion. The division had always used a single vehicle as a forward command post in emergencies such as hurricanes. However, as technology became more important, the division noted that the GIS software needed to be located in a separate trailer, so that dusty firefighters or soaked responders did not damage the sensitive equipment.

The group session concluded with discussions of other disasters and the recently recognized utility of geospatial information technologies. The participant provided an assessment of the utility of GIS, given scale considerations at the federal, state to the local levels.

“So I think when you’re looking at all of the requirements [of GIS] when you start at the federal or state level, you’re looking at a much more dynamic, static environment with big picture issues. When you get down to the county level, you’re looking at a much more dynamic, a much more intensive scale.
Both participants were excited about the rapid growth of GIS use in their organization, and they foresaw great improvements in the next several years. These developments arose from lessons learned in past events coupled with the technological advances in geospatial information technologies. Upon finishing the discussion (total duration 1 hour, 58 minutes), both participants were given exit questionnaires (summarized results appear later). Both participants were asked and agreed to participate in further verification of formalized concept maps and scenarios via follow-up online and phone contact.

5.6 Instantiating the CTA: Charleston County Emergency Operations Center

The final county level EOC visit was at Charleston County, SC. After initial introductions, the participant indicated a separate division was in charge of GIS activities. He indicated his work was primarily with law enforcement, and that they all had first hand knowledge of the area, requiring little map support. The director indicated that only a wall sized county map was used in the EOC, and that GIS were not employed by his staff. He emphasized that the responders in his county had such familiarity with the region that maps were often unnecessary, calling into question the utility of advanced GIS or multimodal technologies for county response and management. He also indicated that the officers and responders were often under extreme time and stress constraints, thus only tacit knowledge of locations or radio relayed directions were practical during emergency situations. The participant decided not to participate in the study.

5.6.1 Exit Questionnaires for South Carolina Participants

Summary results from the exit questionnaires for the four participants (excluding Charleston County) in South Carolina appear in Table 5.4. The questions were divided into two parts, feedback about the perceived utility of a gesture speech interface to a GIS and feedback related to the knowledge elicitation sessions. In questions 1-4, participants were asked to consider the utility of the proposed gesture speech geoinformation system in relationship to their work. Questions 5-16 focused on the knowledge elicitation processes themselves, including issues of scheduling, repetition of methods, and ease learning the concept mapping technique.
<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>State</th>
<th>County</th>
<th>AVG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Using the system in my job would enable me to accomplish tasks more quickly.</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>Using the system would enhance effectiveness and improve my job performance</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>Using the system would make it easier to do my job</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>4</td>
<td>4.25</td>
</tr>
<tr>
<td>4</td>
<td>I would find the system useful in my job</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td><strong>SCALE: 5 = STRONGLY AGREE; 1 = STRONGLY DISAGREE</strong></td>
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<tr>
<td>5</td>
<td>The entire process was difficult to schedule</td>
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<td>1</td>
<td>1</td>
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<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>6</td>
<td>The overall process was comprehensive, adequate, with few redundancies</td>
<td>4</td>
<td>5</td>
<td>4</td>
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<td>4</td>
<td>4.25</td>
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<tr>
<td>7</td>
<td>The concept mapping technique was easy to learn and execute</td>
<td>5</td>
<td>5</td>
<td>4</td>
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<td></td>
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<td>4</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>8</td>
<td>The different colors made it easier to distinguish between subject areas</td>
<td>5</td>
<td>5</td>
<td>4</td>
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<td></td>
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<td>4</td>
<td>4</td>
<td>4.5</td>
</tr>
<tr>
<td>9</td>
<td>Overall, I found the concept mapping exercises helped me relate my work domain</td>
<td>4</td>
<td>5</td>
<td>4</td>
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<td>4</td>
<td>4</td>
<td>4.25</td>
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<tr>
<td>10</td>
<td>I learned more about my own work from the concept mapping exercises</td>
<td>3</td>
<td>3</td>
<td>4</td>
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<td></td>
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<td>3</td>
<td>4</td>
<td>3.25</td>
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<tr>
<td>11</td>
<td>The multiple person concept mapping exercise made it easier to describe my work domain</td>
<td>3</td>
<td>3</td>
<td>4</td>
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<td></td>
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<td>4</td>
<td>4</td>
<td>3.5</td>
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<tr>
<td>12</td>
<td>Overall, I am satisfied with the ease of completed the concept mapping exercise</td>
<td>3</td>
<td>5</td>
<td>4</td>
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<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>The use of the video camera was distracting</td>
<td>2</td>
<td>1</td>
<td>1</td>
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<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>14</td>
<td>Overall, I am satisfied with the amount of time it took to complete the concept mapping exercise</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td>15</td>
<td>Overall, I am satisfied with the entire work domain analysis process</td>
<td>3</td>
<td>5</td>
<td>4</td>
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<td></td>
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<td>5</td>
<td>5</td>
<td>4.25</td>
</tr>
</tbody>
</table>

Table 5.4: South Carolina Exit Questionnaire Results

The results for the state and county visits in South Carolina are merged in the table. The first four questions were related specifically to the utility the participants anticipated if the EOC was equipped with a gesture speech interface to a GIS. For the system related questions, all respondents indicated that such a system would improve their job performance, and indicating it would be a useful addition to the emergency management toolkit. Questions 5-16 were related to
the KE sessions. For these questions, one participant noted the difficulty in scheduling onsite visits. For the most part, participants indicated that the interviewing techniques (concept mapping) were easy to learn. The use of colored Post-It™ notes for distinguishing between categories of concepts also received high rankings. The amount of time required for conducting the concept mapping sessions received the lowest overall average ratings.

5.7 Instantiating the CTA: Florida State Emergency Response Team (SERT)

5.7.1 Introduction

The Florida State Emergency Response Team (http://www.floridadisaster.org/) has its headquarters in Tallahassee and is comprised of approximately 175 employees. The internal division structure at the time of the onsite visits appears in Figure 5.17. Participants involved in the knowledge elicitation exercise reported here included the State Emergency Response Team Chief, the Operations Chief, the Information and Planning Chief, 2 GIS analysts from Planning, and the planning manager for hurricanes. Informal conversations also took place with the Division Director (State Coordinating Officer) and the Public Information Officer, but they were not official participants in the onsite visits.

![Figure 5.17 Florida State Emergency Response Team Organizational Structure](http://www.floridadisaster.org/)

(Source: http://www.floridadisaster.org/)
As noted above, the planned KE exercises in Florida involved many more participants than in the previous field exercises. Individual participation was initially scheduled for four one hour sessions over a 1-2 week time frame. Contact was channeled through a single liaison. Planning the precise schedule for sessions prior to arrival was not possible because all of the participants (including the liaison) were away for exercises and conferences the two weeks prior to arrival (while field work in South Carolina was taking place). A brief phone call conversation with the liaison the Friday before a planned Monday start indicated that only two people would be able to commit to multiple sessions. Other SERT members, if able to participate at all, would have from one-half hour to two hours available, depending on their personal work schedules for that given week.

The effect of the scheduling changes and uncertainty prompted adjustments to the overall structure and selection of techniques. Specifically, initial interviews were scheduled with the liaison and the GIS director. The primary goal of the initial interviews was to elicit a mission scenario. For all other participants, the reduced participation time available was dealt with by rolling several complementary elicitation methods into concept mapping sessions (regardless of length). These included participant information collection, critical incident probes and exit questionnaires. Lastly, no group concept mapping sessions were scheduled.

5.7.2 Participant Information Forms

The organizational diagram above shows the division’s structure and was supplemented with the participant information forms. These data are summarized in Table 5.5. Most participants had been with the SERT for several years, and all participants had over 5 years of experience in their area of expertise (emergency management or GIS). The two most experienced participants had been in emergency management for 17 and 25 years. These participants had been involved with hazard response and emergency management prior to the growth of GIS technologies in these domains. The GIS specialists had several years of experience with GIS and database technologies (one participant’s GIS experience stretched back to early military GIS applications). While not all participants were GIS specialists, most of the decision makers had taken training courses in GIS and had a degree of working knowledge of its capabilities and utility in emergency management.
<table>
<thead>
<tr>
<th>Division</th>
<th>Individual Background &amp; Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Information &amp; Planning Chief, Chief Bureau of Preparedness and Response, Planning Manager, Operations Chief - Community Program Administrator, System Project Administrator, System Project Analyst</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>Responsible for the collection, storage, analysis, and distribution of information during disasters. Also responsible for the development and distribution of IAPs, flash reports, situation reports, situation summaries, fact sheets, threat forecasts, and other related products. Emergency Response Planning Team Chief - run state EOC Operations. Administrator of the response section of the Bureau of Preparedness and Response providing supervision and direction of Domestic Security, Operations, Emergency Planning, Critical Infrastructure, Emergency Services, and Metropolitan units. During disasters, serves as Chief of Operations for SERT supervising 14 of 17 ESFs to accomplish operational objectives and coordinating between state and local response agencies. Head of GIS Division of Emergency Management; Head of GIS for Break and Coastal System, Florida DEP. Develop databases to support DEM work. Collection of data, identification of sources, writing code to manipulate data, and conversion of all data sources into usable formats.</td>
</tr>
<tr>
<td><strong>Emergency Management Training</strong></td>
<td>Event management and information planning. 20 Hurricane planning, transportation planning. Operations, Logistics, Planning and Training. Military GIS. Emergency Mgmt GIS.</td>
</tr>
<tr>
<td><strong>Years in Emer Mgmt</strong></td>
<td>17 8 10 2 6</td>
</tr>
<tr>
<td><strong>Years of GIS Experience</strong></td>
<td>1 0 20+ 2 8</td>
</tr>
<tr>
<td><strong>Years in EOC</strong></td>
<td>17 25 8 10 2 6</td>
</tr>
<tr>
<td><strong>Number of times present during EOC activation</strong></td>
<td>17 D.N.R. All in the 6 year period 25+ 3 D.N.R.</td>
</tr>
<tr>
<td><strong>Types of Emergencies</strong></td>
<td>Hurricanes, wildfires, drought, tornado, floods, red tide, September 11 mass-fatality. Hurricanes, Tornadoes, Blizzards, Train wrecks, Floods, Wildfires, Nuclear Power Plant Events, HAZMAT. 9-11 Terrorist Response; Hurricane, flooding, fire, HAZMAT, etc.</td>
</tr>
</tbody>
</table>

Table 5.5: Florida State Emergency Response Team Participant Information Summary
5.7.3 EOC Tour

When I arrived onsite, the liaison provided a tour of the facility. The EOC in Tallahassee had 5 large screen projected displays at the front of the room (figure 5.18). Within the main room, tables were clustered for individual ESFs. The directors and decision makers staffed a desk directly in front of the large screen displays (center of figure). Smaller adjoining rooms provided facilities for weather experts and conference space for the FEMA Hurricane Liaisons and other decision makers. The primary conference room for briefings and conference calls was located down the hall from the EOC.

![Figure 5.18: View of the Florida State Emergency Operations Center](image)

5.7.4 Initial semi-structured Interviews

The initial interviews were conducted with the Information and Planning Chief and the GIS Director; interviews proceeded in the same fashion as at South Carolina. As in SC, a primary goal was development of the mission scenario to be used in subsequent KE activities. To facilitate design of the mission scenario, the Information and Planning chief used large printed maps of past exercises as well as onscreen HURREVAC outputs of past hurricanes. These maps served as prompts for recalling past events and focusing discussion on scenarios of emergency response. Scenarios included flooding, hoof and mouth disease, nuclear power plant particulate
release creating an ingestion pathway situation, nuclear plume modeling, evacuation routing, drought, terrorism with anthrax, chemical release plume modeling, and finally, Hurricane Wilma.

Hurricane Wilma was a fictional storm used for a previous training exercise. The storm originated in the Caribbean and passed over Cuba before proceeding up into southern Florida. The Hurricane Wilma exercise was chosen as the mission scenario for subsequent concept mapping sessions with the SERT participants. The mission scenario is discussed in detail below. The Hurricane Wilma exercise was familiar to all participants. The familiarity of the scenario meant that the participants would probably only discuss what the team did during the actual exercise, providing more realistic information than if it were a hypothetical storm that they were unfamiliar with. A drawback is that it relies on their memory of the training session, and thus, recall of past events might prevent discussion of alternative situations they had not thought of during the training exercise. The SERT team spends several days a year conducting training exercises that require coordination of counties, individual ESFs relief organizations and the state and federal agencies involved in the response effort. The planning manager suggested that future observation of several of these exercises would probably be the best way to validate the results of this study, and to expand the information base into other aspects of emergency management.
To prepare for these sessions, I used the HURREVAC program to generate thirteen screenshots depicting the hypothetical storm as it approached the Florida coast. The goal of these maps was to prompt participants to discuss specific issues and stages in the process of hurricane preparedness and response. Each map prompt coincided with the release of advisories by the National Hurricane Center (at 3 or 6 hour increments as in real hurricane emergencies). Each of the 13 maps used as prompts were printed in color on 8.5 x 11 paper. Each map was labeled with the day of the week, time of day, and time point within the storm’s progress (e.g., Monday, 8:00 pm, Cat 0, 63 hours out). These prompts (see Figure 5.20 below) represent the same information that planners use for decision making and planning situations during real hurricane emergencies. The maps provided the spatial context for each time period, and the written summary of the storm’s conditions for that time (forward speed, wind speed, etc) provided the temporal context. One item to note, the hypothetical storm for the mission scenario is atypical, in that it rapidly increases in strength right before landfall, creating a difficult situation for emergency managers and first responders. The initial interviews, creation of the mission scenario, and generation of mission scenario prompts concluded the first 1.5 days of the visit.
Hurricane Wilma Mission Scenario

Sunday Evening  
72 hours +

Monday 5:00 am  
63 hours out

Monday 8:00 pm  
48 hours out  
Moving 12 mph

Tuesday 8:00 am  
36 hours out  
Moving 8 mph

Tuesday 11 am  
33 hours out  
Moving 8 mph

Tuesday 8:00 pm  
24 hours out  
Moving 9 mph

Cat 0  
Cat 0  
Cat 0  
Cat 0  
Cat 0  
Cat 1
5.7.5 Procedural Concept Mapping with Mission Scenarios

Concept mapping sessions using the mission scenario detailed above proceeded with a total of six participants over the next 3.5 days. The participants included the Information and Planning Chief, the GIS Director, the EOC director (and former Logistics chief), the Operations Chief, the Hurricane Program Manager and a GIS analyst. The semi structured critical incident prompts and general questions related to the role of maps, collaboration and other activities were integrated, when appropriate, during the procedural concept mapping exercise. While discussing
past events, some participants drew sketches directly on the concept maps to help describe the situation they were recalling. At the end of the session, each participant was asked to complete an exit questionnaire before the conclusion of onsite visit or to mail them back to the Penn State address provided.

Direct participation of participants in the concept mapping session varied significantly. One expert chose to draw the entire concept map, mapping out the entire process with little assistance. Others simply pointed to links and nodes that I had drawn on the concept map, and used them as a referent for recalling what they had said previously, or for describing relationships as new nodes were mapped. In all cases, the timeline and the presence of physical, paper based prompts kept the concept mapping session on track and focused on the mission scenario. They also assisted with recall of past events and as prompts for exploration of new topics related to the mapped information. The presence of other large maps in the room assisted the knowledge acquisition process, serving as another device to prompt more detailed local information (for example, participants indicated specific counties that historically had flooding problems, or showed roads that typically become over crowded during evacuations).

Figure 5.21: Concept Mapping in progress
Participants drew directly on the concept map or used other maps in the conference room to visually augment discussions of past events or past scenarios. For example, one participant drew a map of a river, and the location of well heads and livestock farms, to show how water sampling strategies were conducted and to demonstrate the likelihood of contamination from wellheads covered by flooded farmland. Other participants drew on the maps to indicate how regions were divided into separate areas of operations based on the likely impact point for the Hurricane Wilma storm event. Often, when a participant struggled to describe an event, then noticed the map, they would immediately take advantage of the map’s explicit spatial representation to refocus their attention and relate key geographic aspects of the situation.

5.7.6 Results from the Interview Sessions

The following subsections highlight information collected in Florida about critical incidents and historical events. Recall that in Florida (except for the two initial semi-structured interviews conducted with the Information Planning Director and GIS Analyst) the probe questions were merged with the concept mapping sessions. The information from the probes in both the semi-structured interviews and the concept map exercises is presented in the following subsections. Some examples of the types of critical decisions and incidents participants discussed included evacuation, pre-positioning recourses, ordering logistic aid packages, and deploying recovery and response teams. These decisions require an extensive financial commitment, are characterized by high degrees of uncertainty (about deployment time and specific location), and must be adaptive in order to handle the changing conditions of the particular storm event. Key findings are discussed below.

5.7.6.1 Geospatial Information is Critical to Evacuation Support

For hurricanes, the information and planning director indicated that the critical issue “is where you’re going to evacuate, when you’re going to evacuate and the time frame that you have for evacuation. When that event is going to make the decision to evacuate ... typically we evacuate three areas: surge zone, low lying areas that typically flood outside of the surge zone, and then mobile homes.” An important piece of information needed for each of those regions is an estimate of the evacuation population. Decision makers often select several facilities, regions, or groups of regions in order to obtain a count of the people in that region. Similar queries are made for specific critical facilities as well (e.g. hospital, assisted living facilities, etc).

Using GIS to examine the vulnerability and characteristics of critical facilities is one of the primary activities prior to a hurricane’s landfall. A confounding issue lies in determining
which facilities are classified as critical. During one session, a participant discussed the term critical facilities.

“The counties define what is critical to the survival of the county, and the state is starting to define what is critical to the survival of the state, and they’re not necessarily the same thing. For example the nuclear power plants are not considered critical facilities by the counties, because they have no control over them. But they’re very critical to the survival of the state.”

This statement highlights the iterative process of improvement to emergency management and the use of geospatial information through the standardization of terms and datasets at multiple collaborative levels (state and county).

The GIS director characterized the utility of GIS in the following recollection of information mapped during a hurricane exercise. As soon as the latest NHC advisory was issued, the GIS team plotted the storm track, wind speeds, and warning area. Then, 10-15 senior agency officials discussed where they thought the storm was going to go, and based on the footprint of the high winds and the storm surge, determined the areas to evacuate. Participants in the exercise then focused on locating weak points in the system such as drawbridges and other choke points in the traffic network. The GIS team then produced maps that showed where the evacuation phases had to be in relation to the choke points and the timing of the storm to help the decision makers determine the timeframe within which the people had to be evacuated and to make preparations in case the timeframe was not met.

5.7.6.2 The collaborative use of maps

One participant recalled a time when several emergency managers used a topographic map to collaboratively prioritize response efforts. Flooding had taken out 49 bridges in North Carolina and fifty families were stranded on one side of the creek and one needed medical assistance. The immediate tactical response was to use a helicopter to swing load medical supplies and food to stranded individuals. The next activity focused on providing access to a personal item distribution point (to provide food, ice, personal hygiene products, clothes, etc) and shelters. They had a short time frame to build several bridges across the creek. Maps were used to find shallow areas to deploy a logging mat (chain wire mesh mat for moving heavy equipment). But they still needed more locations to create bridges in order to get the families out within the timeframe declared by the director. They used the map to identify the depth of the creek bed with the confluence of feeder creeks to build fords. They were notified they had procured a pontoon bridge from the DOT and they used the map to place it near the densest cluster of houses.
Multiple participants discussed using maps to determine the best locations to place resources. Particularly important were GIS constructed ‘Battle Maps’ for collaborative planning meetings. ‘Battle Maps’ depict resource locations of the state’s deployed resources (logistical staging areas and advanced recovery and damage assessment teams). They are also enlarged to show specific details such as county EOC locations and distribution centers. These planning maps help inform collaborative decisions, such as determination of the area of operations, prioritization of response efforts, resource deployment and tracking, supply convoy routing, and evacuation zone determination during planning meetings.

5.7.6.3 Collaborative Communication with a Map

Another historical event involved a situation where collaborative communication between a team in the field and the EOC was augmented by the use of a map and a GIS to help prioritize recovery and damage assessment operations. An ‘A team’ (Advanced Response Team) was deployed at the site of the flooded creek. Flooding along the creek had damaged a diesel fuel tank, and the tank had ruptured. Communicating with the EOC via phone, the ‘A team’ used a topographic map to describe the locations of damaged buildings and facilities and the extent of the flood. They also described the location of the ruptured fuel tank so that the EOC could estimate how far fuel had traveled down stream to deploy a team to conduct booming operations.

During this phone conversation, managers in the EOC plotted the relayed information in a GIS. The EOC workers plotted the flooding extent, sectioned off the city, and marked damaged buildings. Using that information, they discovered that flooding had covered a water treatment plant, and contaminated raw sewage had flowed into the town’s buildings (the community services building, a daycare center, and an elementary school). Based on that damage, they established several point locations to conduct water and soil sampling. In all, the A team helped the EOC workers identify the flooded region, the damaged buildings, as well as 20 residential houses in the GIS. Maps containing the damage reports and sampling strategies were printed and given to the damage assessment team as they left the EOC.

5.7.6.4 Implications for Large Screen Displays

One participant indicated that a constraint on the utility of maps in time critical situations used to be the time it took to print the large maps. And in the planning rooms, sometimes it was difficult to clearly see the printed maps. The participant noted:

“If you have a great big map, and everyone can reasonably, clearly see it, and you’re standing up there saying, these are the places where our assets are deployed. These are the areas where we need to send them into. It’s much easier
to do that with a map than it is to say, well, wait a minute, how close is Alachua to Brevard County. A lot of things become self evident.”

The participant also indicated that they were working to get large flat screen TVs in the planning and conference rooms where most of the decisions were being made. That would allow them to show the real-time displays of the multiple mapping technologies used in planning (GIS, HURREVAC, Satellite Imagery, etc).

“To me, words are almost useless in a high stress, immediate decision-making contexts. Whatever we can do to map it out and make it easy for people to digest is by far the way to go.”

The participant suggested that large format maps (printed or digital) allow the directors to ask questions such as ‘why are you recommending that we evacuate starting at 7 o’clock in the morning?’ and the hurricane program manager could show the map depicting the evacuation timings. Highlighting the importance of large maps during disaster planning and response, the participant indicated that part of the reason maps were not used more frequently in decision making contexts in the past was the length of time it took to have them plotted. He indicated that the maps were critical for making decisions because they helped eliminate speculative discussions of how close one area was to another. To help overcome the time required to plot maps, the GIS team had begun to develop easy to use interfaces to allow decision makers and response personnel real-time access to the geospatial information.

5.7.6.5 Maps for Emergency Support Functions & Decision Making

As detailed above, Emergency Support Functions (ESFs) are divisions of collaborative decision-making teams with members from emergency management, state and local agencies, and private and government organizations that handle specific situations and help coordinate resources during all phases of emergency management. The role of the SERT team is to provide support for the individual ESFs. The field activities in Florida included attention to the role of ESFs and the ways maps and GIS are (or could be) used to support that role. Most participants indicated that for hurricanes specifically, all of the ESFs used maps and that the maps played major roles in the crisis management process. For hurricanes specifically, three were identified as higher priority functions: Transportation, Communications and Public Works and Engineering. However, the sheer size and impact of hurricanes requires the coordination of all ESFs. Specific to providing geospatial information support, one participant noted:

“The priorities for [ESFs] change as the storm approaches the coast. Some of them we never deal with. Some ESF functions, you never provide support for
[information and maps]. In other cases, the priorities change from low priority to high, and then after the fact go away. Some of them don’t come into effect until after the fact, in recovery. Some of them are important during preparation, have low importance during the actual event and have high importance after the fact.”

Meeting the needs of decision makers in SERT and ESFs requires efficient, non-redundant, map production. To accomplish this, requests for maps are channeled through an information and planning officer or a GIS liaison. Of those requests, a GIS specialist indicated:

“I would probably say 95% of the work that we do is georeferencing, or giving them a georeferenced picture of where something sits in reference to something else. Showing layers, and showing maps of where something is in relation to something else.”

Another participant noted that a primary application of GIS during a hurricane was to determine where the storm was headed, the severity, and what resources needed to be moved out of the path of the storm. Several participants indicated that a movement towards making GIS more transparent and electronic was rapidly occurring. Newer capabilities to support information queries and damage assessments were being made accessible online. To illustrate, a participant noted:

“We’re starting to bring online querying ability like, you can select an area, I have this many hospitals, how many beds are available in this many hospitals. We can do the same thing with shelters, we can select an area and determine how many beds are available in those shelters.”

A clear movement towards improving access to geospatial information was actively underway in Florida. The GIS team was developing new interfaces for on screen display and web based access so that the information could be used to inform decisions and emergency management response activities.

5.7.6.6 Maps to Support Situational Awareness

Rapidly obtaining situational awareness is critical in emergency management. One participant discussed this need in terms his own heuristic: “the three call rule.” The first call received by the EOC indicates that the situation is a complete disaster; the second call indicates that the situation is not as bad as previously thought; by the third call to the EOC, the decision makers begin to obtain a clear picture of the situation.

“I’ll give you an example last year I got a call we’ve got to evacuate 20,000 people because of a fire. 15 minutes later, I get a call saying, well no it’s not 20,000 people, it’s maybe in the area 5,000 people we’re going to have to
evacuate. Third call I get, now it’s down to maybe 20 homes we have to evacuate.

The participant noted that the most immediate need was to improve the decision maker’s situational assessment of the disaster. A specific goal in relation to situation assessment is to identify some of the complex collaborative tasks that occur during time critical, emergency response efforts that currently rely on static, paper maps that potentially could be improved by more advanced geospatial information systems. The following is a summarized account of one such task.

In the state of Florida, reports on emergencies and damaged areas are phoned in to county and state emergency recorded telephone lines from multiple law enforcement, recovery, and county agencies. Each of these calls are then manually input into an online web-based system called TRACKER, allowing collaborative access for everyone in the EOC as well as the broader emergency management community. In the past, the reports that are now released as online bulletins in TRACKER were manually plotted on large maps hung on the walls of the planning rooms.

A participant recalled a past hurricane when emergency managers had plotted damage reports on a map on a bulletin board near the Intel room. When a damage assessment and recovery specialist saw the map, he indicated that he needed that information to help conduct post impact damage assessments from a helicopter all over the impacted area in South Florida. The information plotted on the map represented a complete list of targets for him to assess, and would save several hours of flight time because (without this information) the damage assessment specialist would have had to conduct a grid search over the entire area until he found individual targets. They were able to get the information to him, but every point had to be plotted in a gazetteer before the recovery specialist could leave.

As emphasized above, placement of damage assessment teams and recovery specialists and resources during the first 24-48 hours is crucial, and any improvement to existing technologies during that period, would be advantageous to emergency managers. Elaborating on this issue, a participant indicated “I guess the hardest thing is getting a handle on the situation, and it usually takes a couple of hours [for any disaster], whether it’s a fire, etc.” The emergency managers dispatch regional coordinators to the scene, but it often takes more than an hour to arrive at the disaster location. The participant concluded, “So until I’ve got my own eyes and ears on the ground there, I’m in the blind here [the EOC].”
“You’ve got the ‘golden 72 hours.’ And in those 72 hours, what’s going to happen in the first 24 hours, people are victims and they’re in shock. Second 24 hours, they realize they’re victims, and they’re going to try to help themselves. And that third 24 hours, if they’re in a catastrophic event, they’re going to realize they can’t do it themselves, and they’re going to expect the resources to be in place.”

The participant emphasized that it takes about 48 hours to get resources deployed, thus, the first 12 hours are critical for identifying the nature of the catastrophe so that resources can be deployed rapidly. A second participant indicated that impact assessment during the first 12-24 hours was critical.

“We basically have a reasonably short timeframe to determine what has been impacted as far as infrastructure. What do we need to do from the state and even from the local perspective in order to put humpty dumpty back together again, both with respect to infrastructure, continuity of government,…power restoration…road clearing…”

He further emphasized that the goal is to identify what happened and based upon that initial damage assessment, to decide the size and type of provisions to distribute in relief supply zones. Obtaining and improving emergency managers situational awareness during disasters is a critical issue, and real-time geospatial information is often critical to accurately understand the extent of a crisis situation.

**5.7.6.7 Dealing with Uncertainty in Human Behavior**

During the onsite visits, the experts mentioned several sources of uncertainty in human behavior that can influence emergency response activities that can affect the plans implemented by the emergency managers. The experts indicated they needed to know information like:

- Do evacuees take their boats and RVs?
- What’s the population for a given holiday weekend?
- How can evacuation patterns be predicted, monitored and mapped?
- Which individuals are most/least likely to evacuate?
- What areas are most/least likely to evacuate?
- How far do evacuees travel?
- Where do evacuees go?
- What percentage will utilize shelter resources?
- Which shelters are preferably selected over others?

Participants suggested that, if they had such data about human behavior, they could develop mapping and modeling capabilities of human behavior so that they could make better predictions
of evacuation clearance times, the number of shelters to open, and the number of resources
needed to support seasonal population fluctuations.

5.7.6.8 Map Support for Briefings and Reports

Damage assessments of wind, flood, and surge impacts represented another more
advanced GIS mapping capability that had recently been adopted. The GIS analysts create maps
that depict damage estimates for specific structures (single family homes, mobile homes, etc) and
then generate a dollar figure of the estimated damage for larger regions. The maps and the
resulting information are combined into documents created by the Information and Planning
division that provide decision makers with damage assessments for a given storm. The dollar
projections and analyses are then incorporated into a letter written by the division director
requesting a Federal Disaster Declaration and relief funds. At the state level, another important
use of maps is to support EOC briefings about emergency response preparation. Briefings are
conducted twice a day to the entire division (with individual counties connected remotely via
teleconferences). The maps help the decision makers describe the activities and actions being
conducted across large geographic regions and identify areas where resources should be relocated
or in need of further support.

5.7.6.9 Mapping Real-Time Data

Regarding the information required for effective emergency management decision
making, the EOC director stated that “Basically, I need location, hazard, impact, resources, and
locations to stage resources. Those are 5 critical things.” That information is all time critical, and
must be converted to usable formats (often maps) and continuously updated in real time.
Specifically, a participant noted, “In emergency management if it’s more than 48 hours old, it’s
history, as far as we’re concerned. Because in 48 hours we’ve got crews on the ground doing
surveys from the ground or by helicopter with their acetates actually marking the damage.”
Highlighting the ephemeral nature of geospatial information in emergency situations, a GIS
specialist noted: “We have found that 90% of the maps requested were short term usage and a
visual on the screen will do just as well as a paper copy. And a visual on the screen is a lot faster
than a paper copy because it takes 10-15 minutes to plot out a paper copy.”

In Florida, efforts are underway to develop a complex, modeling and monitoring system
for traffic management and evacuation support. This new technology was discussed during an
interview with the All Hazards Planning Manager for the State of Florida Division of Emergency
Management. When asked if other geographic information needed to be integrated with the
traffic data, the participant responded:
“It might be helpful. Right now we just don’t have that level of sophistication, we just don’t have that capability. We’re sort of on the verge of doing things rather dramatically different than we have heretofore. One of the things that we’re actually doing is developing a system, where by we will be able to dynamically manage evacuations.”

Specifically, the efforts were aimed at integrating traffic data with the evacuation zones in order to preemptively predict traffic volumes for different decisions. This system would be aimed at improving planning activities and exploratory evacuation modeling in order to help decision makers weigh all options to reach informed decisions. The system is currently being collaboratively developed by the National Highway Administration, the Department of Transportation, and private industry for use in the state of Florida. Traffic modeling is only one example of a dynamic representation of geospatial information that can improve crisis management. Resource tracking, damage assessment tracking, and restoration of services such as communications and power represent other efforts that could be improved through visual display of real-time information.

5.7.6.10 Problems in Mapping

Two primary, map-related, causes for past breakdowns in decision-making activities were identified a) the data were not available or b) the information requested by the decision makers could not be depicted on a single map. Related to an instance where data availability hindered mapping and the use of geospatial information, one participant noted that tonnage loads of bridges on county roads were not known, but that the knowledge was needed to adjust evacuation routing. Similarly, another participant recalled a time where flooding had blocked a major highway that was used for relief supply distribution. At the time, the height of bridges on alternative routes was not known, thus they were not sure if the large supply trucks could fit under the bridges and deliver the cargo. Since then, those data have been collected and compiled into the database. Other similar instances had prompted the GIS team to collect and compile information about airport runway lengths (that could receive air cargo or alternatively, be used as distribution sites), landfills (that could create water pollution problems), or dams (potential targets for terrorism).

The second problem was that the data decision makers needed could not be displayed at once. The resulting displays were cluttered with too many symbols (a term the division called the “measles effect.”) The ‘measles effect’ occurred most often when individuals had limited knowledge of the location and the density of the GIS database. In these cases, an individual might request a map of all the critical facilities for a county. A map displaying all of the facilities
would be unreadable, so the GIS team has built a plug-in interface that allowed individuals to select categories of data for onscreen display that separates the information by hazards, infrastructure type, and the critical facilities for a specific ESF.

5.7.7 Exit Questionnaire

All participants completed the exit questionnaires. The results of their answers and the summary statistics are included on Table 5.6, below. The findings were essentially the same as those from South Carolina. The participants indicated that scheduling was a bit difficult (likely

<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>Florida SERT</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Using the system in my job would enable me to accomplish tasks more quickly.</td>
<td>5 4 5 4 2 4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Using the system would enhance effectiveness and improve my job performance</td>
<td>5 4 5 3 2 4</td>
<td>3.83</td>
</tr>
<tr>
<td>3</td>
<td>Using the system would make it easier to do my job</td>
<td>5 4 5 4 2 3</td>
<td>3.83</td>
</tr>
<tr>
<td>4</td>
<td>I would find the system useful in my job</td>
<td>5 4 5 4 2 4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Scale: 5 = Likely; 1 = Unlikely**

<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>Florida SERT</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>The entire process was difficult to schedule</td>
<td>1 4 5 2 2 3</td>
<td>2.83</td>
</tr>
<tr>
<td>6</td>
<td>The overall process was comprehensive, adequate, with few redundancies</td>
<td>4 5 5 4 4 4</td>
<td>4.33</td>
</tr>
<tr>
<td>7</td>
<td>The concept mapping technique was easy to learn and execute</td>
<td>5 4 4 3 4 3</td>
<td>3.83</td>
</tr>
<tr>
<td>8</td>
<td>The different colors made it easier to distinguish between subject areas</td>
<td>4 4 3 4 5 4</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>Overall, I found the concept mapping exercises helped me relate my work domain</td>
<td>3 4 3 3 3  DNR</td>
<td>3.2</td>
</tr>
<tr>
<td>10</td>
<td>I learned more about my own work from the concept mapping exercises</td>
<td>2 4 4 3 3  DNR</td>
<td>3.2</td>
</tr>
<tr>
<td>11</td>
<td>The multiple person concept mapping exercise made it easier to describe my work domain</td>
<td>N/A N/A N/A N/A N/A 0</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Overall, I am satisfied with the ease of completed the concept mapping exercise</td>
<td>4 4 4 3 4  DNR</td>
<td>3.8</td>
</tr>
<tr>
<td>13</td>
<td>The use of the video camera was distracting</td>
<td>1 2 1 2 2  DNR</td>
<td>1.6</td>
</tr>
<tr>
<td>14</td>
<td>Overall, I am satisfied with the amount of time it took to complete the concept mapping exercise</td>
<td>5 4 5 3 4  DNR</td>
<td>4.2</td>
</tr>
<tr>
<td>15</td>
<td>Overall, I am satisfied with the entire work domain analysis process</td>
<td>5 4 5 3 4  DNR</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Table 5.6 Summary of Exit Questionnaire: Florida SERT
due to alterations to the schedules during week of the visitations). No participants indicated that they felt the camera to be a distraction during concept mapping interviews.

5.8 Chapter Summary

This chapter provided a detailed account of the activities and information collected during onsite visits with emergency managers in South Carolina and Florida. The onsite portion of the research was aimed at obtaining detailed information about emergency management activities during hurricane planning and response. This information was intended to provide a deep understanding of work with geospatial information and technologies and to obtain specific information that could be incorporated into scenarios that simulate work during hurricane response. The following subsections discuss the implications of the information reported in this chapter related to the development of an improved understanding of hurricane response, geospatial information technologies, and the onsite approach to knowledge elicitation.

5.8.1 Improved Understanding of Hurricane Response

5.8.1.1 Decision making direction and control

At all locations, the most important and complex decision discussed was the order to evacuate. Control over evacuation decision-making varies from state to state. In Florida and North Carolina (except in rare events where the governor orders a mandatory evacuation) the decision to evacuate is left up to the individual counties in the storm’s path. The state and county officials collaborate via conference call, and discuss the options given the current threat, and then the county retains autonomy and issues the necessary evacuation orders and protective action recommendations. If the counties become overwhelmed, they can request that the state take control of the situation, but in general, the state agency acts as a facilitator to assist and provide support (in the form of personnel, resources, supplies, etc) to the local responders in the vulnerable counties.

In South Carolina, the state Emergency Management Division collaborates with the county managers via conference call to discuss the evacuation considerations for a given event. However, the governor ultimately determines the type of evacuation and the timing for when the order is issued. As a check and balance, counties have the opportunity to request the state to take over direction and control of county operations at any point, however generally, the state acts as the lead agency for coordination of response related activities. The county officials direct the resources under their control, and coordinate with the state agencies who are leading the response efforts.
When studying emergency response and management, it is important to understand the hierarchical social-organizational structure of each specific organization’s decision making activities. Direction and control of response activities varies among states and counties across the entire nation and researchers should focus on characterizing states and counties by their structure in order to develop a general sense of decision making activities across and between states and counties.

5.8.1.2 Emergency Support Functions

As discussed earlier, Emergency Support Functions carry out the specific tasks in emergency response. FEMA designates 12 ESFs to structure organizations and resource delivery during emergencies. Across all sites, the ESF-1, Transportation was indicated as critical to immediate hurricane response activities (because of its role in evacuation support). Other critical response activities included Mass Care, Communications Support, and Public Works and Engineering.

State level officials in South Carolina and Florida indicated that ESFs differ among states. While most states use the first 12 ESFs designated by FEMA, other ESFs were developed internally to carry out specific duties at the state level. In Horry County, the participants indicated that ESFs not only differ from state to state, but also vary between the county and state levels. For example, one state-specific ESF added by South Carolina (ESF-16 Evacuation and Traffic Management), supports state level activities during evacuation; however at the county level, such activities were actually carried out by the ESF in charge of Law Enforcement.

Field researchers with a specific goal, such as understanding evacuations, should focus on researching the individual agencies that are in charge of the ESFs. For example, to understand how evacuations are conducted in South Carolina, a state level focus with the DOT would be important. To study county level evacuations in South Carolina, the focus should be on the individuals directing and controlling the law enforcement communities.

5.8.2 Implications for Geospatial Information Technologies

This section discusses issues that can help improve access to geospatial decision making information and technologies. Specifically, the section addresses GIS integration, interoperability, data standardization, data sharing, interface design, and improved public access to geospatial information.

No single geospatial information technology supports the full range of decision making activities in emergency management. To date, an interoperable and integrated platform for sharing information and overlaying multiple types of information remains elusive. Instead, state
and county emergency managers use multiple geospatial information technologies to meet their decision making needs. For pre landfall decision making, HURREVAC, HURRETRAC, CATS, TAOS, and the division’s GIS are used to produce maps that inform the determination of when and how to evacuate. Other weather information, including satellite imagery, sea-surface temperature, SLOSH models, and weather buoy data are also displayed on maps and distributed to decision makers. While some technologies have begun to combine and provide overlays of information (for example, HURREVAC combines evacuation data with weather data), most are designed to support a specific purpose, and are not integrated into a single spatial decision support tool. Some of the tools, such as shelter status monitoring, display lists of information, and are not spatially referenced at all. To develop advanced geospatial information technologies that support emergency management activities, a system needs to be designed that integrates the capabilities of these legacy technologies so that information access can be achieved through a single mapping system.

The use of GIS differed in terms of personnel, technologies, and extent of use across states and counties. In South Carolina, a single GIS Analyst works either in his office or a GIS room located adjacent to the EOC. Data displayed on the analyst’s personal computer in the GIS room can be routed to the large screen display in the EOC. Requests for spatial data (almost always critical facilities) made by decision makers and ESFs are relayed via the EOC operations director. The director tasks the GIS specialist with producing onscreen displays or paper maps of the requested, specialized data. Precompiled base maps are loaded and modified to support individual requests. As new information or requests for spatial data are received, the analyst maps and displays it accordingly. The other primary real-time function is the creation of new layers depicting necessary updates given the current situation. For example, road construction and wrecks are relayed via the DOT and road layers are relabeled as obstructed and out of use (indicated by red).

In Horry County, a team of GIS specialists worked to create and update maps and provide that information to the decision makers. Systems such as ArcIMS were being used to help disseminate real-time map information in the EOC and to the public. The information was then relayed (via phone) to responders in the field during emergency events. The county level operations were also focused on the integration of mobile devices, and mechanisms for coupling that field based information into a centralized database. The state level GIS analyst discussed the variability of GIS use across the state, noting that some of the counties (such as Horry County) had detailed GIS departments whereas other counties had no GIS support.
In Florida, in part because of the higher population and higher number of coastal counties that are vulnerable to hurricanes, a team of GIS experts collaboratively support the division’s needs. They were working to improve the interfaces to GIS so that decision makers could more easily access the information without the help of a GIS specialist or extensive training courses. The GIS team was focused on building and maintaining an accurate, up to date database of all of the critical information in the state. They were also working on developing redundant systems that could be loaded into trucks and deployed at disaster field sites, getting the imagery and maps into the hands of the workers in the field. This focus on improving the mobility of the information and the distribution of geospatial information to first responders, field commanders, and damage assessment teams represents an important movement of geospatial information technologies.

Despite efforts to improve GIS access in decision making contexts, data and software interoperability, interface design, and information access remain obstacles to widespread dissemination of geographic information. A wide variety of stand alone mapping technologies were used for displaying geospatial information at different states and counties. And while the specific proprietary GIS software vendors varied among sites, all sites had either adopted, or were migrating exclusively to ESRI GIS software. Data standards, storage formats, and database systems were not consistent across states and counties visited in this study, and are probably variable across the entire country. Because emergency management is highly collaborative, and often, over-taxed agencies have to bring in emergency response experts from other state agencies, it is important to develop common operating practices to coordinate collaboration. Such a common view can assist the responders in heavily impacted areas; to meet this goal, the development interoperability and data sharing standards are needed.

5.8.3 Implications for the Approach

CTA has seldom been used to study work with geospatial information and technologies. Thus, one contribution of this dissertation is to assess and extend CTA methods for application in this domain. The onsite work for the CTA used multiple converging techniques that could be flexibly adapted depending on the constraints posed upon arrival to work with experts. These two aspects were critical to the success of the onsite visits. One of the most important aspects of these visits was the access they provided to the actual tools, datasets, maps, and examples of products they produce during emergency events. HURREVAC, for example, is a restricted access program; however, the onsite visits allowed me to explore how it is used in the context of emergency management decision making.
Critical incident probes provided mixed results depending on participant domain expertise. When used with experts having several years of experience, they provided some of the most useful information. I highly recommend the use of these types of probes for onsite work. For example, at one point, after recalling several past events, a critical incident probe helped the participant recall the first use of GIS in hurricane response in Florida – post Andrew. Specifically, the participant said, “You know I hadn’t thought of it until just now,” indicating the recall of a historical account of GIS use. He continued to detail the first use of GIS to produce large planning maps immediately after Hurricane Andrew in 1992. Specifically, a GIS was brought in right after the event and used to create an E size plot of the impacted region for the FEMA briefing to all responders. They used it to determine their operations area and to track the locations of supplies such as water and ice, food supplies, relief organizations, Disaster Medical Assistance Teams, Disaster Application Centers (DACs), etc. Similar maps produced by the GIS were used from then on to support briefings and collaborative planning meetings with officials from numerous organizations (US department of Health, FEMA, EPA, DOE, military, the FEMA defense coordinator, Florida DOT, USDOT, American Red Cross, etc). The participant said,

“You talk about blowing some people away. Man it blew them away. They were not ready for anything like that; they didn’t think anything like it existed. But [the director] put it up there, and said ‘this is what we’ve got.’ And you knew that we had turned the corner, with this [GIS] technology, we had turned the corner.”

Critical incidents provided information in detail such as the above discussion, and procedural concept mapping was the means for capturing knowledge about the current events, activities and decisions involved during hurricane response. (The resulting procedural concept map models produced from those interviews are presented in Chapter 6). I found that using large sheets of paper on the table as the base for constructing the concept maps seemed to place the participants in a working mode, in which they were an active contributor. They were motivated to demonstrate the information they were discussing, in essence, teaching me the material.

Not all participants actively wrote on the paper with markers and moved Post-Its™ as expected; for some participants, I constructed most of the representation with their guidance. However, even in these cases, when the relationship between concepts that the participant felt were related was not clearly indicated, they took an active role in describing the relationship so that they could be represented correctly. These participants would point at items and demonstrate how they should be connected, or moved. They also were quick to identify items that were not placed in the correct position or for which the relationship was not described adequately.
Creating mission scenarios prior to concept mapping was a necessary step to maintain consistency in each of the procedural concept mapping sessions. The concept map provided a useful medium through which communication was focused and channeled. The concept map helped to focus the participants on the task at hand, and the specific hypothetical hurricane event. The start, middle, and end of the sessions were apparent to the participants, and thus, unlike open-ended interviews, an endpoint was implied by the linear nature of the timeline-based concept mapping.

The changes to the knowledge elicitation exercises that became necessary during the onsite work emphasize the need for highly flexible plans. Initially, the plan was to spend 1-1.5 hour sessions working with each individual participant (thus 2 in Columbia and 6-8 in Florida). Then, results from all of the participants would be used to create a single mission scenario to guide the procedural concept mapping sessions at that site. Upon instantiation, it became clear that a mission scenario could be derived by working with a single expert. The elicitation of that scenario, however, was not as straightforward as previously expected. It was difficult to identify an appropriate event, and even more difficult to determine the exact spatial and temporal elements that would serve as the prompts. The specific details about a) what a mission scenario was, b) how to elicit one, c) what format to present the scenario to the participants, and d) how many steps it should have) evolved over the course of the onsite visits.

The details of mission scenarios also varied between states. For South Carolina, a ‘typical’ storm that would require full activation was determined to be a Category 3 hurricane with a track centered on Columbia, and thus, affecting the entire South Carolina coastline. Hurricane Fran, in 1996 exhibited this exact condition at one point but veered off to the north. For the mission scenario developed, the hurricane would continue directly on its track centered on Columbia. The storm drives the OPCON classification levels, which in turn drives the decision making activities in South Carolina. Thus these transitions served as the temporal cues for defining the mission scenario used to elicit the procedural concept map. The Hurricane Program manager provided access to the Hurricane Plan, which outlined all of the major decisions that had to take place given that timeline. Hurricane plans contain the procedural information for building mission scenarios, and (if possible) should be obtained and summarized before conducting onsite CTA fieldwork.

As mentioned earlier, in Florida, I was allowed to examine the HURREVAC software program (a critical geospatial information technology used in evacuation decision making). HURREVAC storm files are available for historical storms, and these files were used to build the
mission scenario. The storm file was used to print maps and event related prompts for procedural concept mapping. It also allowed me to replicate how external information from other agencies (e.g. the release of specific forecasts from the National Weather Service) impacts transitions between levels of activity in the EOC. The exercises in Florida were structured with thirteen printed HURREVAC map outputs as prompts for procedural concept maps (compared to the five OPCON stages in South Carolina). Because HURREVAC is not generally accessible to researchers, I could not have generated realistic prompts (i.e., like those used during real hurricane response activities) without eliciting the scenario onsite. A key difference between the two types of prompts used in the mission scenarios was that the OPCON prompts used in South Carolina reflected the specific temporally structured stages that are traversed during an event as indicated in the hurricane plan and the activation levels of the EOC. In Florida, the HURREVAC outputs replicated the way that information is disseminated to decision makers during an actual hurricane event. To elaborate, the corollary to South Carolina’s OPCON levels are EOC Status Level 3, 2, and 1 (full activation), and when the decision makers received a specific prompt during the mission scenario, then they indicated that the activation level would or would not increase (allowing for more consideration of alternatives). In South Carolina the timing was driven from OPCON 5 to 1, with discussions of work focused on the change in OPCON level without viewing HURREVAC outputs as they are received during actual events. To conduct a realistic recreation of such an event, the decision makers would need to receive prompts every 3 hours as they are released from the NHC from the time the storm is identified until impact.

Although planned prior to field work, group concept mapping sessions were not conducted in Florida. The original goal for all sites was to redraw each individual concept map before group sessions, and then use edited maps to highlight similarities and linkages between the multiple workers. Because of the complexity of the procedural concept maps in Columbia, SC, they could not be redrawn in the time allotted. Instead, the two participants were asked to examine the two maps created in the interviews, identifying instances where they collaborated with each other. It was difficult for participants to interactively examine their concept maps and attempt to identify similarities. Summarizing the maps was complicated by the large size, linkage complexity of nodes, and the variations in length of the procedural concept maps. Rather than trying to relate the information on the concept maps, the participants decided to demonstrate the process they would follow for displaying geospatial information on the large screens in the EOC during the early stages of hurricane response. This serendipitous reenactment provided detailed information that was more similar to actual work in practice than information collected solely on
the procedural concept maps. The reenactment is complementary to the other approaches, and served to progressively expand the collection of domain knowledge. It also provided knowledge via artifact based transactive memory (or action based use of knowledge) yielding new recognitions and mutual learning. This allows more experiential, intuitive use of knowledge to break through the enactment, simulates real world conditions, hence making it similar to participant observation fieldwork of an actual event without the associated stressors.

The only true, group concept mapping session, proceeding from a blank slate with the two participants in Horry County, was successful. Often, the session consisted of a dialogue between the two division participants (brainstorming strategies of how they should or would proceed). This brainstorming (similar to the reenactment of the Columbia participants) was based on their communication in practice. Their dialogue yielded information about past events and future plans (discussed earlier), as well as helped to fill in the concept maps.

One important aspect of the group session in Horry County was that one participant left the room twice, and the other once, each time for 5 – 15 minutes. While away, the other participant was able to expand the procedural map according to his own expertise, and upon the other participant’s return, that participant clarified the information that had been related by their colleague. This ‘see saw,’ interrupted concept mapping yielded useful information, perhaps because a single participant was not able to dominate the session, and instead, both collaboratively related their experiences.

Flexibility, again, was the dominant theme of the entire onsite process. For example, the visit to Horry County was scheduled for one hour with one individual but expanded to more than 3 hours with two participants. Moreover, both participants were available at the same time, and thus concept mapping had to be carried out with both participants at once rather than individually as planned for. This changed the nature of how the timeline anchor can be used in concept mapping. For example, in the Pilot’s associate development project (McNeese et al. 1990), a timeline was used to structure concept mapping based on known stages for acquiring a military target. Those steps were universal for that specific task. The stages before an emergency do not match to a specific task, as the tasks are different and constantly changing depending on the event and the responsibilities of the individual involved. In my approach, the center line represented the individual being interviewed, with actions and activities of the individual emanating from the center line at specific times. When two participants were interviewed simultaneously, the participants were represented as nodes, and the centerline represented only time, separated by OPCON levels. During the group session, it was helpful to have one participant exit for a period
of time and then return to help fill in the map. If similar breaks and interruptions were planned into group concept mapping activities, it could improve team based knowledge elicitation exercises like procedural concept mapping.

In Florida, the scheduled time allotted for each participant was significantly reduced from the original plan. This situation required the KE sessions to be collapsed from multiple interviews to a single interview. Specifically, the original plan called for individual interviews with all participants followed by individual concept mapping sessions, the time constraints only allowed completion of the first stage. Further, some participants had only a short window for knowledge elicitation. Thus, for those experts, the questions and critical incident probes from the semi-structured interviews were used opportunistically during the concept mapping sessions with domain experts.

If onsite work were conducted again, I would emphasize and prioritize the selection of the mission scenarios in advance (however, I did not have access to the software and data that they use during emergencies until I visited the locations in person). In the future, the specific event timing could be obtained via the hurricane plans accessible on the internet or by phone interviews. Moreover, several short mission scenarios could be developed in advance (with the help of a single liaison) allowing the researcher to address a wider range of emergency management contexts (such as specific decisions in one type of event, or similar decisions across several types of emergencies).

In all, the onsite visits yielded a wealth of information spanning multiple scales and types of work. Each technique yielded a different form of information. Critical incident probes and questions related to maps and GIS provided historical context and future challenges. The mission scenarios and procedural concept maps provided structured information about the tasks, decisions and information requirements in emergency management. By merging critical incident probes and general questions about map use into the knowledge elicitation exercises, the sessions never seemed to get ‘bogged down’ with awkward periods of silence. Instead, the entire process flowed to a logical conclusion, ending in reflections and projections of the future utility of GIS and geospatial information technologies in emergency and crisis management. To place the information in a larger context, the end of the sessions migrated away from hurricane response specifically, and focused on the role of maps for all disasters and emergency situations.

In chapter VI, the formalized concept maps that represent procedural models of hurricane response are presented. Individual summaries and collective summaries of the information are provided. The content of the concept maps are summarized according to information
requirements, decision support needs, and other information that has implications for technological design. Finally, information collected at all stages of the CTA is merged into Abstraction Hierarchy models of the work domain (to show the organizational structure) and decision making models (to provide more detailed information about specific decisions). In Chapter VII, all of the information is combined into scenarios of emergency management activities.
Chapter VI:
Modeling the Domain

“Everything should be made as simple as possible, but not simpler.”
-- Albert Einstein --
6.1 Introduction

A core component in Cognitive Task Analysis is the creation of models of the work domain. In the previous chapter, the onsite activities and results from specific interviews were presented. In this chapter, I present the formalized models that were produced from the information collected during the onsite activities with emergency management experts. These models represent the structure of the work domain, the process of work activities, and the information processing required for decisions in emergency management.

First, I present initial models of the structure of hurricane emergency preparedness, response and mitigation represented as abstraction hierarchies. Next, I present the procedural concept map models of the work activities during hurricane response to highlight the process of hurricane response. They contain information about individuals, their decisions, and their information requirements during hurricane response. I discuss the process of converting the interview maps into draft versions of formalized procedural concept maps. Next, the discussion focuses on the stages of validating these draft formalized concept maps. Summary results for each individual concept map are presented followed by collective summaries of the concept map content. These collective summaries are presented as lists of the emergency management decisions during hurricanes, the decision makers involved, and the information required to make informed decisions. Finally, decisions are explored in further detail. The decision making process of South Carolina and Florida are examined. Decision ladders are presented that map the collaborative decision making activities required to issue an evacuation during hurricane emergencies.

6.2 Exploring Structures of Hurricane Response with Abstraction Hierarchies

Abstraction Hierarchies provide information about the structure of the domain of emergency management. Recall from Chapter II that Abstraction Hierarchies are a means for structuring knowledge in order to understand the means-ends and whole-part relationships of a work domain. The hierarchy is intended to help researchers understand a work domain through iterative development of a deep understanding of work.

The Abstraction Hierarchy (as a modeling procedure) was developed as a means of capturing the context of the overall system within which supervisory control operators worked (Rasmussen, 1986). The idea is that a system can be modeled and understood by breaking it down from the abstract to the concrete (y axis / means end) and from the global to local (x axis / whole part). Most authors choose their own labels for the X and Y axes as well as their specific methods for constructing them (Rasmussen, 1986; Vicente, 1999; Potter et al., 2000). No single
A lot of effort has been placed on expanding the utility of the abstraction hierarchy by applying it to new domains. Here, I have used the abstraction hierarchy to examine the structure of work in emergency management.

Figure 6.1, below, shows that at the top left portion of the hierarchy, the information should answer why something is done. Traversing from left to right, the information presented changes in scale from the global to elemental level (whole-part) and thus, national response to municipal responders. Traversing from top to bottom (means-ends), the structure depicts a range from high level goals such (to save lives), through abstract functions that help to achieve the goals (ESF: SEARCH AND RESCUE), to the physical form of search and rescue teams and first responders (police officers and firemen). By examining the level below, one can examine how something is done, and by examining the level above, one can determine what is being done.

**Functional/Structural Model of Multiple Levels in a Domain**

<table>
<thead>
<tr>
<th>A B S T R A C T</th>
<th>G L O B A L</th>
<th>E L E M E N T A L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response &amp; Recovery</td>
<td>FEMA</td>
<td>STATE EMD</td>
</tr>
<tr>
<td>Functional Purpose</td>
<td>The highest level goals of a system</td>
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</tr>
<tr>
<td>Priorities &amp; Values</td>
<td>Specific approaches for prioritizing actions to achieve those goals</td>
<td></td>
</tr>
<tr>
<td>Abstract Functions</td>
<td>A conglomeration of multiple generalized functions to meet specific goals</td>
<td></td>
</tr>
<tr>
<td>Generalized Functions</td>
<td>Processes that combine multiple physical functions</td>
<td></td>
</tr>
<tr>
<td>Physical Functions</td>
<td>Behavioral characteristics of a physical object</td>
<td></td>
</tr>
<tr>
<td>Physical Configurations</td>
<td>A physical object in the world</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.1: Why, What and How of an Abstraction Hierarchy
Before discussing the three hierarchies I developed (for Planning and Preparedness, Response and Recovery and Mitigation), I want to note that I found it difficult to match the complex socio-technical system to Rasmussen’s levels in the hierarchy. This issue was particularly complicated when deciding where to place items in the middle levels of the Abstraction Hierarchy. Specifically, it was difficult to differentiate between general functions and abstract functions as they related to the relief organizations. I found that it is easier to understand the utility of the Abstraction Hierarchy when examining smaller systems and beginning at the physical configuration level. To illustrate, at the physical configuration level – ice, generators, and food are physical components of relief supplies. Each one has its own physical function (to preserve food, provide electricity, and provide sustenance). These supplies are ordered, organized and distributed by collaborative efforts of ESFs and relief organizations, placed at the generalized function level. Establishment of mobilization sites is an abstract function of emergency management that is carried out to support “provision of relief.” The priorities and values of a mobilization site are to provide adequate resources to affected individuals in a timely fashion, and at the highest functional level, the goal is to help people recover. By examining this smaller system, the abstraction hierarchy is helpful in developing an understanding the structure of the work domain and the means ends relationships among the levels.

Abstraction hierarchies have generally been used describe such smaller, technical systems and not vast socio-technical systems such as the federal to municipal levels of the emergency management domain. This work does not attempt to duplicate Rasmussen (1986) but instead, builds on those foundations. I have populated the hierarchies for three major phases of emergency response activities related to hurricanes. These hierarchies provide a basic framework for understanding the domain of emergency management relative to hurricanes. Information collected during the offsite and onsite visits as well as the content of the concept maps were used to populate the three hierarchies included in figures 6.2, 6.3, and 6.4. It is important to note that hierarchies produced below do not contain all federal to local and functional to physical entities for all aspects of emergency management (a daunting task for a team of researchers). The three hierarchies correspond to planning and preparedness, response and recovery, and mitigation specifically. These abstraction hierarchies are preliminary attempts to model the range of emergency management activities from the federal to local level.

A primary reason that Rasmussen cited for developing the abstraction hierarchy was to help in developing an understanding of the interactions between the highest level of a system (the
goals) and the lowest level (the physical implementations that help achieve those goals). In my experience, I found it easiest to identify the high level goals in the abstraction hierarchy. For each of the three hierarchies I created, I identified the strategic goals for all aspects of emergency management at the functional purpose level. All emergency responders’ activities (regardless of whether they are federal, state or local) are guided by these three goals, which are essentially to protect lives and property and ease suffering through a speedy recovery.

![Abstraction Hierarchy of Planning and Preparedness](image)

**Figure 6.2: Abstraction Hierarchy of Planning and Preparedness**

In the abstraction hierarchy for planning and preparedness (Figure 6.2), the second level of the hierarchy (priorities and values) presents the means with which the high level goals of planning and preparedness activities are met (taking action to lessen the impact of hurricanes on their residents). Abstract functions to support this goal include sheltering, improving public awareness and providing training. These activities are accomplished by a range of organizations (such as ESFs for logistics, operations, military support, etc.) that are classified at the generalized function level. Their physical functions include the activities that they conduct to meet the higher level goals (conducting meetings, planning evacuations, prepositioning resources, conducting
training exercises, etc). The physical configurations include the teams that work to distribute the information and specific information that helps them accomplish their goals. Also at this lowest level are the specific tools that ensure effective communication, collaboration and action.

Figure 6.3: Abstraction Hierarchy of Response & Recovery

Similarly, in response and recovery operations, the goal is to help the communities rebuild and repair by providing adequate food, shelter, and financing. Multiple ESFs are in charge of meeting the higher level goals. These agencies and organizations coordinate their response activities through physical functions including statewide meetings, distribution sites, mobilization sites and logistical staging areas. At the lowest level of the hierarchy, the specific items provided to the individuals at the physical configuration level include food, ice, water, toilets and generators, etc.

An important point to make is that an abstraction hierarchy is scalable, in that a single entity on a hierarchy could be placed at the lowest level of physical configurations or physical form, and examined according to each level above. So, while I have placed fork lifts, shelters, generators, etc at the physical configuration level, one could instead place an ESF, such as
Logistics at the physical configuration level and extract deeper relationships in the levels above on the hierarchy. Similarly, the goals of logistics could be placed at the functional purpose level, and the specific subcomponents and physical configurations of that ESF could be examined. In a complex socio-technical system like emergency management, the ability to iteratively examine the subcomponents of the system can provide an improved understanding of the domain.

<table>
<thead>
<tr>
<th>Mitigation</th>
<th>FEMA EMD</th>
<th>STATE EMD</th>
<th>COUNTY EMD</th>
<th>MUNICIPAL EMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional Purpose</td>
<td>Strategic Goal 1: Protect lives and prevent the loss of property from natural and technological hazards</td>
<td>Strategic Goal 2: Reduce human suffering and enhance the recovery of communities after a disaster strikes</td>
<td>Strategic Goal 3: Ensure that the public is served in a timely and efficient manner.</td>
<td></td>
</tr>
<tr>
<td>Priorities &amp; Values</td>
<td>Reducing the damage caused by hurricane winds and flooding through improvements in the built environment, including residential and non-residential buildings and their utility systems.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstract Functions</td>
<td>Developing hazard mitigation construction guidelines</td>
<td>Recommendations to state &amp; local programs</td>
<td>Assessing building performance</td>
<td>Redesigning plans</td>
</tr>
<tr>
<td>Generalized Functions</td>
<td>Logistics</td>
<td>Information &amp; Planning</td>
<td>Information &amp; Planning</td>
<td>Resource Support</td>
</tr>
<tr>
<td></td>
<td>Finance &amp; Admin</td>
<td>Operations</td>
<td>Environmental Protection</td>
<td>Public Works &amp; Engineering</td>
</tr>
<tr>
<td></td>
<td>Public Safety</td>
<td>Law Enforcement</td>
<td>Energy</td>
<td>Volunteers &amp; Donations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mass Care</td>
<td></td>
</tr>
<tr>
<td>Physical Functions</td>
<td>Rebuilding or existing buildings</td>
<td>New building codes</td>
<td>Insurance requirements</td>
<td>Software updates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Training requirements</td>
<td>Interoperability assessments</td>
</tr>
<tr>
<td>Physical Config.</td>
<td>Workshops, seminars</td>
<td>Workshops, seminars</td>
<td>Workshops, seminars</td>
<td>Workshops, seminars</td>
</tr>
</tbody>
</table>

Figure 6.4: Abstraction Hierarchy of Mitigation

The final hierarchy is concerned with mitigation. Mitigation focuses on reducing the damage from future hurricanes by building and establishing building codes and other regulations. At this level, abstract functions include the establishment of new building codes and insurance laws and technological upgrades. Generalized functions collaboratively work to carry out these higher level goals and instantiate those goals through the creation of new building codes and laws that reduce a community’s vulnerability to hurricanes.

I found that the abstraction hierarchies were effective in developing an initial understanding about the relationship between the highest level goals of emergency management.
and the manner in which those goals are met by teams of individuals collaborating to accomplish specific tasks. In creating these versions, I discovered that more information is needed about the interactions of ESFs, relief organizations, and their specific physical work activities in order to develop a deeper understanding of work and tasks of emergency management responders. These three hierarchies, while obviously not populated with all possible components of emergency management suggest that emergency management has a deep structure at the abstract level. ESFs, relief organizations, and Emergency Response Teams coordinate in meeting the highest level goals of the emergency management community. What is not clear is the individual priorities and interconnections between individual ESFs and relief organizations (i.e. who collaborates with whom to achieve specific tasks and meet the high level goals). While these specific abstraction hierarchy models provide a high level understanding of the work domain of hurricane management, they are only an initial starting point for developing a robust and expanded understanding of the interconnected structures within emergency management.

After using this modeling tool, I think that the Abstraction Hierarchy is most appropriate for examining narrowly defined components of the socio-technical system of emergency management (such as the earlier example where I described the components of a mobilization site).

6.3 Reviewing and Editing Concept Maps

The Abstraction Hierarchies helped identify the structure and functions of the domain; concept maps were used to understand the process of hurricane response. Concept mapping sessions yielded six concept maps of varying depth and detail. The process of formalizing the concept maps consisted of several steps aimed at producing consistent representations of the elicited information. The process followed was similar to that delineated by Zaff et al., (1993). Transcripts of the video taped concept mapping sessions were used to validate the content of each field-generated concept map and to add missing information that was related by the interviewee, but not captured in the maps during the short interview sessions. Concept nodes and links were edited and augmented as needed, based on the video tape and the paper transcripts of the interview text.
Emergency responders have multiple duties and diverse responsibilities during hurricanes. The information the participants provided yielded concept maps with high degrees of variation for all stages of hurricane response. I had a goal to develop an understanding of teamwork and collaborative emergency response activities by making comparisons between concept maps. In order to address this goal in the analysis, the concept maps had to be displayed adjacently with a timeline of consistent length and common origin. When they were aligned in this way, I was able to examine multiple maps for similarities and differences among the work activities described by the participants and produce summarized results.

Not only did the formalized maps need to be displayed adjacently, the concept maps also needed common attributes. Specifically, color coding was assigned to key themes in order to enable easy comparison of those themes across maps (see Figure 6.5). Red was used for event related information, which includes information directly related to the specific hazard scenario (e.g. hurricane path error swath, storm category, etc). Yellow was used to depict the features and infrastructure that were vulnerable to the event. Orange was used for at risk populations such as the population in the flood zone, evacuees, etc. Green represents the infrastructure and physical resources that were used for response (shelters, comfort stations, relief supplies, etc). Blue indicated the people, agencies, and teams involved with response efforts. Gray was used for all technologies, information, and tools (GIS, computer software, etc). Finally, purple was used to indicate actions, decisions and other work related duties. Specific actions include the decision to evacuate, the prepositioning of resources, etc).

To illustrate the difference that results from application of the coding scheme, a black and white and a color version of the same portion of the Florida Operations Chief concept map are presented in the following Figures 6.6 and 6.7.
To locate information related to decisions on the black and white version, the reader would need to examine the entire concept map. On the colored version, by focusing on only the purple nodes, the actions and decisions for that stage become salient. Likewise, focusing on the orange nodes allows a reader to assess vulnerable populations of importance at a given temporal period. By stepping away from the maps (in essence, zooming out) color can be examined relative to all of the concept maps, providing information about the nature of teamwork and collaboration, or information requirements.

The relationships depicted in the concept maps contain significant variance. The relationships that link concepts are generally expressed as verbs or propositions. In the concept maps developed for emergency management, a majority of the relationships were verbs that expressed the actions of the participant’s tasks (e.g. monitors, recommends, affects, notifies, requires, considers, reallocates, collaborates with, etc.). Other relationships contained a degree of causality or a temporal component (e.g. leads to, can cause, will yield, results from, repeats until, begins, lasts until, prior to). Hypothetical instances were also another type of relationship contained on the concept maps, examples include: could be, can occur when, and should use. The participants also used terms that related to desire (would like to have, would want access to, and would need to see). Some of the relationships (especially those about resources) described elements of spatial interdependency (have, within, outside of, contain, that lie on, are located on, are located near, deployed in, are stored at etc.). Another distinct category of relationship were those that described concept relationships of generalization (are a, of, type of, kind of, are also called, which is a). Instances are another category of relationships contained on the concept maps (for example, e.g., such as). Synonyms were also a relationship used to describe the domain (like, similar to, is also called, represents the). The diversity of the relationships and propositions makes a single categorization difficult to create. Here, I have aggregated the relationships into several general types to assist with interpretation of the kinds of relationships related on the concept maps. Note that often, relationships also contained adverbs and adjective modifiers to indicate importance or priorities.

Figure 6.8 (below) depicts an overview of the concept maps generated from the Florida work. The time span of each map is identical (based on the mission scenario timeline) and the major driving forces (hurricane watch, warning and impact) line up in the light red, vertical columns in the figure. This presentation style affords concept map examiners the ability to identify holes in the concept map space. A hole in the concept space could be a result of a decline in an individual’s activities for that period, and thus, a function of work, or it could
indicate missing information, and thus a hole in understanding. Similarly, the reader can focus on dense node clusters (representing areas of detail and often, important concepts). Concepts with multiple links emanating from a single node also indicate important information points. Examination of holes, clusters, and links within the concept space can help focus future research.

After the draft formalized procedural concept maps were completed, they were returned to the emergency managers for verification. Each participant received the 11 x 60 inch formalized procedural concept map, an instruction packet and a self addressed, stamped return envelope. The participants were reminded that the representation was a single instance of their
work activities during hurricane response, and thus, would not have all of the activities captured. They were also reminded that the representation was specifically based on the mission scenario discussed during knowledge elicitation sessions (and was not a general model). The complex process of emergency management could be represented a number of ways, and this procedural concept map representation was only one such method. The representations were abstractions that transform detailed interview scripts into models of the process of work.

Participants were asked to validate that the map captured and represented their work activities for the specific hurricane event scenario. Specifically, each participant was asked to validate the content of the map, and indicate whether it was an accurate representation of their work practices and return them in the Self Addressed Stamped Envelope provided. They were also given the option, if they chose, to complete the following, more detailed validation process.

- identify incorrect information contained on nodes or links and cross out those nodes that do not belong or re-label node with the correct information
- add any essential missing nodes or links
- circle problem areas
- indicate suggested adjustments to content
- identify the key decisions in the processes represented by the concept maps
- distinguish between actions and decisions by placing stars next to decisions
- validate order of decisions by placing stars with numbered labels next to the nodes (e.g. *1 – evacuation of keys *2 – traffic reversal *3 – preposition LSAs)
- identify the key themes or stages within the process important to their work (e.g. evacuation monitoring, data preparation, etc)

6.4 Interpreting the Concept Maps

Concept maps are representations that afford the reader the opportunity to identify themes, clusters, unions, intersections, and linkages among related concept nodes. The task of summarizing information on concept maps requires the analyst to identify key ‘kernels’ – clusters of concepts related to a single important concept. Zaff et al. (1993) suggest that the kernels assist with development of a global understanding of the problem domain. Zaff et al. (1993) advocate four heuristics for identifying the key ‘kernels’ contained within concept maps. First, one should identify areas with a large number of connected concepts. These regions indicate in-depth discussions of the material and are likely to be important to the overall theme. Second, a kernel should be the parent of several generations of concepts. The third aspect is that key kernels should also be invariant across multiple concept maps. Fourth, one should identify declarative phrases associated with the concept such as “this one is important.”

McNeese et al. (1999) suggests that the success of concept map representations can be measured in their ability 1) to facilitate information transfer from one individual to another, 2) to
identify the key ideas in a subject area, 3) to provide a formalism closely analogous to the mental organization of the expert, and 4) to summarize a given cognitive domain. Zaff et al (1993) indicate that the concept maps should provide understanding of nuances of the knowledge domain, identify variation, dynamic situations (so they can be planned for in an expert system), identification of the expert’s conception of problem areas such as unpredictable situations, problems with data, and the identification of information requirements.

The concept maps produced here achieve these same goals. The concept maps helped identify global characteristics in the knowledge domain while capturing the overall complexity of specific decision making activities in the domain. The concept maps should also help identify key concepts for the organization of future research, the identification of the general domain knowledge as well as the key decision points along a time continuum. The identification of information requirements is accomplished by examining what information is needed, what form it is in, how it is used to make decisions and how that knowledge is communicated amongst collaborators.

I have adopted an approach to analyzing the concept maps similar to that outlined in Zaff et al. (1993). The remainder of the chapter applies this approach to analysis of the concept maps. Specifically, it focuses on the identification of key decision making activities in hurricane response, key concepts, problems facing the emergency managers, and the information requirements they need to support decision making activities that were elicited during concept mapping sessions. These themes are discussed first in terms of each individual’s concept map and ultimately in summary tables and diagrams for the aggregate of all concept maps.

Figure 6.9 below shows a small scale version of a single completed concept map. Figure 6.10 shows an enlarged version of a portion of that concept map. To facilitate analysis and comparison of concept maps produced, each concept map produced adapts the following common features.

- The centerline represents the interviewee (the Horry County map is an exception, and to help differentiate individuals, each centerline has been assigned a unique color)
- Temporal information appears on the centerline (e.g. -48 hours before landfall)
- Lines emanating from the centerline represent the actions taken by the interviewee at that time
- Events with specific times (e.g. HURRICANE WATCH @ 21 hours before impact) are placed directly on the timeline.
- Lines emanating from nodes placed ON the timeline represent actions that result from that event at a particular time
6.5 Individual Summaries of Concept Maps

The following sections provide summary results of the content of the formalized procedural concept maps. The concept maps from South Carolina (state and then county) are
presented first, followed by Florida. Because the concept maps are representations of an individual’s work during the hypothetical hurricane, they are presented individually.

6.5.1 South Carolina Hurricane Program Manager

The concept map produced with the South Carolina Hurricane Program Manager is included in its entirety, split into figures on the next four pages. This map was not only verified, but the participant completed all of the additional verification activities described above. A common theme across all of the nodes is the presence of an action item (Tropical Depression X appears), followed by data collection, and recommendations for increasing the OPCON level. Collectively, the OPCON levels depict the increased activity level of not only the Hurricane Program Manager, but also the entire Emergency Management Division.

Hurricane response activities initiate upon detection of a tropical storm (Figure 6.11). In this stage, the main duty performed by the hurricane program manager is the collection, examination, and assessment of weather data from multiple sources. This information influences when an evacuation is ordered, and the Hurricane Manager must synthesize it and make recommendations to the director. A primary source of information is the HURREVAC application. Based on analyses of the weather information and HURREVAC program, the manager notifies the division supervisors of the storm and makes recommendations based on the current information.

Figure 6.12 depicts a portion of the concept map with detailed information about collaboration among agencies and responders. In this figure, OPCON stages 4 and 3 are traversed based on the approaching storm, and data layers that would impact evacuation timing are created for evacuation planning discussions. In Figure 6.13, decision making activities increase significantly, and the hurricane program manager recommends evacuation based on the projected storm track in the hypothetical Hurricane Bertha mission scenario. The EMD raises the activity level to OPCON 1 as soon as they recommend a voluntary evacuation. In Figure 6.14, the hurricane program manager’s duties wind down, and he discusses maps and information that will be required for response and recovery efforts.

One specific issue noted in verification was that during the voluntary evacuation, decision makers reevaluate whether a mandatory evacuations is needed, and if they determine that it is, they re-examine when to issue the order. The influencing factors for making the mandatory evacuation decision are 1) the success of the voluntary evacuation (traffic density, estimated number of evacuees, etc) and 2) the storm track and forward speed of the hurricane. Given these
factors, if the decision makers determine mandatory evacuations are required, then recommendations are made to the governor and a mandatory evacuation is ordered.
Figure 6.11: South Carolina Hurricane Manager Concept Map Part 1
Figure 6.12: South Carolina Hurricane Manager Concept Map Part 2
Figure 6.13: South Carolina Hurricane Manager Concept Map Part
Figure 6.14: South Carolina Hurricane Manager Concept Map Part
6.5.2 South Carolina GIS Analyst

A key theme from the concept map produced with the GIS Analyst in the SC EMD was the iterative process of receiving incoming information from multiple sources and continually updating the GIS layers used for map production. One set of nodes (not in the figure below) displayed the analyst’s indication that 75-90% of GIS use in emergency situations was map production. Decisions and events were the primary factors influencing map production. For example, a mandatory evacuation decision for a given county would prompt extensive map production of critical facilities in the flood prone regions of those counties. Information on these maps would include power outages, sewer line locations, surface water contamination, bridge failures, washed out highways, etc. The evacuation would prompt the need for more sets of maps in two themes, shelters and law enforcement. Shelter status maps (full, open, special needs, closed) would be created for decision makers. Maps of traffic control points, road conditions, reversals, evacuation routes, road blocks, and evacuated regions would be needed by law enforcement officials to manage the evacuation, protect from looting, and assist in recovery. A portion of the concept map related to GIS use and data manipulation right before hurricane impact is depicted below. Specifically, the concept map displays the need to update the database with real time information such as shelter status, damaged infrastructure and flooded regions.
Figure 6.15: Portion of South Carolina Emergency Management Division GIS Analyst Concept Map
6.5.3 Horry County EOC Summary

A single concept map was produced for Horry County (Figure 6.16). In contrast to the other concept maps discussed, this map integrated the ideas from two individuals into a single map. As a result, the individuals were represented by concept nodes (in blue below) instead of by the centerline. The stages and prompts with this pair of participants were the progression through OPCON stages as the hypothetical Hurricane Bertha approached. OPCON stages appear on the centerline. The individuals whose activities are represented in the map are the County Emergency Response Director and one of the lead County GIS Technicians.

![Portion of Horry County Group Concept Map](image)

In verification of this map, the director indicated that the concept map was a very good representation of their work processes during hurricane response activities. An element captured on this concept map was the importance of detailed, local information. For example, at the county level, they are extremely concerned with estimating the “tourist profile” (not shown in this
portion of the map). Depending on the time of the year and the particular weekend, the tourist population can undergo significant fluctuations. These fluctuations occur seasonally, monthly, and weekly (individual holiday weekends and special events create spikes in the tourist population). For example, the 4th of July can bring an additional 400-500,000 people to the county; this population must be supported during emergencies, increasing the strain on local resources. Uncertainty about tourist population can create problems for evacuation planning and sheltering at the country level, and a deeper understanding of this variable, migrant population is needed.

The director is in charge of coordinating and managing city, county and state emergency response personnel in the evacuation, preparedness, and recovery operations for the county. In preparation for the storm, the director indicated a need for damage estimates that have specific dollar values for damaged infrastructure; this information is essential to expedite the distribution of FEMA monetary assistance.

6.5.4 Florida Information & Planning Director

The theme that characterizes the Florida information and planning director’s concept map is the provision of up to date information (about the storm, the population, the infrastructure, the evacuation, etc) to the decision makers, counties, ESFs, and the public. The director supervises a team of employees who develop flash reports (descriptions of the threat recommended actions), situation reports (detailed lists of actions), briefing slides, planning and response maps related to all aspects of emergency events. The GIS department is a subdivision in Information and Planning. Figure 6.17 depicts issues that the Info and Planning chief discussed related to preparations for special needs populations based on past events. He also discussed the deployment of mobile teams of highly specialized and diverse personnel. These teams are deployed in advance of the approaching storm and establish immediate disaster field offices in order to perform localized damage assessment mapping, resource management, and collaborative communication with the EOC. The composition of the team is highlighted in the bottom right of the figure 6.17 (blue and gray nodes).
6.5.5 Florida EOC Director

The Florida Emergency Operations Director focused on the timely ordering, procurement, deployment and staging of resources for response. Important issues included uncertainty in the storm (path, strength, speed), the high cost of response activities, and the necessity to have resources in place to rapidly respond to the hurricane’s destruction. As illustrated in the image below, upon receiving information that a storm is heading towards the...
state, immediate activities include requests for event related information, discussion of resource deployment, and the increase in activation level. These are actions represented by lines emanating from the central timeline in Figure 6.18. The EOC Director also discussed the deployment and importance of forward damage assessment teams; these teams act as the ‘eyes and ears’ for decision-makers located in the EOC.

Figure 6.18: Portion of Emergency Operations Center Director’s Concept Map
6.5.6 Florida Operations Manager

The dominant theme represented in the operations manager’s concept map is an account of the composition of aid packages, response resources, and the prepositioning of emergency supplies in the period right before impact and distribution during the immediate response efforts. Prior to hurricane landfall, at the 48 hour mark, the operations chief discussed the current method for tracking deployed resources – pinning metal tags on static wall maps. They also track information with pencil and paper. The participant indicated that map based computer tracking system would be an improvement due to the highly collaborative nature of the response efforts. For example, the operations division works closely with the logistics team and relief organizations to provide relief supplies to the mobilization sites within the first 24 hours of impact. The participant emphasized the importance of real-time communication between damage assessment teams in the field, disaster field offices, logistical staging areas, mobilization sites, and the Emergency Operations Center. The discussion of the activities in the immediate post impact period appears in Figure 6.19. The information depicted covers several aspects of hurricane response ranging from range of event related information, to decisions, down to specific resource needs such as the delivery and provision of portable toilets, dumpsters, feeding stations and generators. Specific details such as number of National Guard soldiers operating a given mobilization site are tracked on paper and pencil checklists. The operations chief indicated

Figure 6.19: Post Impact Activities in Operations
that spatial layouts like military battle boards had the potential to assist with the deployment and management of resources in the immediate response efforts.

### 6.5.7 Hurricane Program Manager

Scheduling constraints allowed for a very brief session with the Hurricane Program Manager. The dominant themes of the session were evacuation decision making, evacuation monitoring, and the collaborative discussions required to make those decisions. The timing of the decision making process is specifically linked to the content and timing of National Hurricane Center advisories made by the National Weather Service. For example, when the National Hurricane Center issues a hurricane watch (which means hurricane conditions are possible in the next 36 hours), decision makers will generally recommend voluntary evacuations of special needs populations for the counties in the watch area. When the NHC issues a hurricane warning (which means hurricane conditions are expected within the next 24 hours), directors follow with mandatory evacuation orders. The advisories are a driving force for decision making activities during hurricane response. Complicating the process, however, are the specific evacuation clearance times for individual counties. More conditions are possible in the next 36 hours), decision makers will generally recommend voluntary evacuations of special needs populations for the counties in the watch area. When the NHC issues a hurricane warning (which means hurricane conditions are expected within the next 24 hours), directors follow with mandatory evacuation orders. The advisories are a driving force for decision making activities during hurricane response. Complicating the process, however, are the specific evacuation clearance times for individual counties. More
populated counties can have evacuation clearance times in excess of 33 hours. The decision makers must consider all of these uncertainties while preparing to recommend voluntary or mandatory evacuations.

A second theme appears in Figure 6.20. During an evacuation, the Hurricane Program Manager spends time monitoring evacuation routes and real-time traffic counter information in order to tailor evacuation decisions. The participant discussed a collaborative effort to develop a Florida Decision Support System, with an emphasis on evacuation decisions. A component of the technology was a map based interface to real-time traffic data. The role of real-time information is mentioned as an active research and development effort by multiple state and federal agencies and corporations working to improve emergency response decision making.

A third major theme appears in Figure 6.21. The hurricane program manager provided a detailed account of the information that damage assessment teams require during the immediate impact of the storm. The participant indicated that information requirements included projected damage swath, and pre-landfall damage estimates based on models and forecasts built on past storms. The projected swath of the storm is overlaid in a GIS and the data are queried for the number and location of vulnerable populations (such as mobile homes).

6.5.8 Florida GIS Director

The complete concept map for the Florida GIS director is presented on the following four pages. In the first Figure 6.22, detailed information about data sources, data files, data management and GIS operations is represented. GIS specialists manipulate geospatial information and provide it to decision makers by using multiple software packages. The GIS team integrates data from HURREVAC (wind swaths) into the GIS to create planning maps. Two important modeling and mapping programs are CATS (Consequences Assessment Tool Set) and The Arbiter Of Storms (TAOS). CATS is a program that integrates with ArcView to produce damage estimates. TAOS is a simulation and modeling GIS that uses live data feeds of oceanographic and meteorological conditions (wind, waves, water) and predicts their affects on the environment (natural, built-up, and human). The shapefiles and model outputs from these packages are integrated in the GIS to produce maps and data tables to assist with evacuation timing, disaster projection modeling, and dollar damage estimates. As soon as the EOC activates for a tropical storm or hurricane, these modeling and analysis packages are used to generate data that can be displayed within a GIS. The models are run at 3-6 hour intervals from the moment of activation until the storm is no longer a threat.

The second figure (Figure 6.23) represents the GIS director’s discussion of event related prompts that are driving forces for map production and decision making activities. For example,
when the storm enters the Florida Straits, evacuation orders would follow. To support the evacuation requires the production of specific maps requested by decision makers on a case by case basis. Database preparations and updates for the oncoming storm are finalized at this point and the modeling activities continue as before.

In the third figure (Figure 6.24), the activity levels of the GIS team decrease until immediate storm impact. A discussion of the information that would be mapped during the immediate impact stages are discussed in this ‘waiting period.’ Specifically, the teams would begin preparing to support advanced reconnaissance and damage assessment teams. A member of the GIS team would be deployed with the advanced SERT team (or A-team) near the impact area to handle mapping and data requirements for the responders and decision makers at in the impacted area.

In the final stage, represented in Figure 6.25, the manager discussed hypothetical scenarios that would likely occur in an event similar to the mission scenario. The participant noted that hurricanes can be categorized by their hazards as primarily rain events, surge events, or wind events. He hypothesized that the storm in the mission scenario, Hurricane Wilma, would likely have been a rain event storm, and thus would have created vast flooded regions. The GIS team would be tasked with identifying the flooded regions by examining imagery, creating coverages of the flooded region, rubber sheeting the flood region polygon with the base map and then overlaying water treatment plants, farms, sewage treatment facilities and landfills. Flooded regions that contain farms and sewage treatment plants will cause contamination of local water supplies. Contaminated water supplies must be identified, the public has to be notified, and provisions must be made to provide safe drinking water to the affected regions. Maps of the regions, queries by population, and location of logistical staging areas all influence the deployment of potable water for the affected citizens. The GIS team would assist with the recovery operations by coordinating with the Department of Environmental Protection. The DEP requires specialized maps of the contaminated areas in order to a) notify the public of the contaminant, b) display locations for obtaining potable water and c) establish water sampling operations to get original water supplies back online. The above paragraph highlights the utility of procedural concept mapping for eliciting expert information about specific work tasks and hypothetical scenarios given a particular situation (in this case, flooding caused by Hurricane Wilma).

The GIS director’s concept map contains a range of information related to the processes of obtaining and managing data, storing and producing maps based on the data, updating datasets with new storm related information, and finally, the discussion of specific situations requiring
map creation that could potentially occur during the rapid response and recovery phase of a rain or flooding event.
Figure 6.22: Florida State Emergency Response Team GIS Manager Concept Map Part 1
Figure 6.23: Florida State Emergency Response Team GIS Manager Concept Map Part 2
Figure 6.24: Florida State Emergency Response Team GIS Manager Concept Map Part 3
Figure 6.25: Florida State Emergency Response Team GIS Manager Concept Map Part 4
6.5.9 Florida GIS Analyst

The concept mapping session with the Florida GIS analyst produced one of the most detailed concept maps of all the sessions. The concept map was focused on the collection, storage and distribution of geographic data. The storage formats, the type of database, and the creation of new data were discussed in detail. Another theme was the role of the GIS analyst as a negotiator of what information the decision makers want displayed on the concept maps. The uncertainty of a hurricane’s impact and strength influences map production activities. The scale and scope of decision making activities narrows as the storm approaches; with the narrowing, the scale of information and maps also becomes focused. For example, at 72 hours out, the analyst would focus on database readiness for a wide swath of counties, and slowly narrow that scope down to specific counties and subdivisions as the storm approaches.

Crisis management is a collaborative effort with multiple individual decision makers and ESF personnel from multiple agencies (SERT, DOT, FEMA, DEP, etc). One node cluster in the concept map represents a discussion of the role of geospatial information as an intermediary between the ‘agencies with questions’ and the ‘agencies with answers.’ In order to provide adequate information to the appropriate party, the GIS technicians work with agencies and organizations (Red Cross, DOT, etc) to obtain data and distribute the mapped information to other agencies and decision makers. The yellow nodes of (figure 6.26 below) represent facilities and infrastructure within the damage path. Specifically, the nodes indicate the information requirements of decision makers at periods of time before the impact of the hurricane; the gray nodes indicate the GIS operations and modeling tools used to display that information.
During verification of the formalized procedural concept map, the GIS specialist provided new information related to ongoing changes in the work practices of the GIS team. Specifically, the team has focused on developing and improving custom built interfaces to geospatial information. The goal is to improve individual decision makers’ and EOC workers’ access to electronic data and information at all times. In the past, decision makers would request maps of critical facilities. Now, the improved access to the information has switched the focus to the specific datasets and information. Moreover, the GIS team has worked to educate decision makers and crisis responders about what types of geospatial information they have and the representation strategies for its presentation. They had also changed the focus from specific hazards and emergencies to three stages: before, during, and after events. The team has proactively worked to brainstorm and obtain all possible types of datasets that emergency managers might need for any given event. To quote, “If the files have to be built as the event unfolds, the GIS staff will be overwhelmed in short order. A GIS unit cannot predict all possible disasters; but, they can have a format for a type of disaster (hazmat, tornadoes, flooding, etc) and know the status of the data sets they would need to help respond to that event.”

The GIS analyst also produced a generic view of GIS activities as a storm approaches Florida. This representation only captures activities from 72 hours before impact until 12 hours after
impact. GIS and mapping activity significantly increases in the post impact period (support as requested). This structure outlines specific times and the activities of GIS analysts during hurricane response.

-60 hours  Ensure state-wide files are current (or updated)
-36 hours  Any special files built (depends on watch area)
-24 hours  Wait for “impact area” determination
-12 hours  Create local displays from existing files to show traffic flow, flooding, etc.
0 hours  Impact Assessment - depends on time of day
  Daylight impact can be assessed as soon as the storm has passed
  Nighttime impact has to wait until morning for impact assessment
+8 hours  Build files to show the location of comfort stations, logistical staging area locations, open roads, damage status of power, drinking water and sewage facilities (and transmission lines)
+12 hours  Support as requested.

These stages capture the participant’s model of mapping activities before hurricane landfall. During the immediate response and recovery stages, geospatial information requirements increase significantly and continue for days, weeks and even months after an event. This information suggests that to improve our understanding of GIS use in emergencies, future research needs to focus on the mapping activities that occur after impact.

Because of the diversity of approaches to emergency management across federal, state and local levels, the participant emphasized that studies of work in emergency management need to focus on answering the question of “who is in charge” of the response. In Florida, for example, the command and control structure is clearly defined and established due to the frequency of hurricanes in the state. Other states, however, do not have clear central authorities for emergency response activities, and instead operate under cooperative agreements of jurisdictional responsibilities between states and response agencies. He suggested that the concept maps and other models of work in emergency management would be improved by investigating the decision making activities and the situations that arise when central commands are absent (e.g. post 9-11 and Hurricane Isabel).

6.6 Exploring Procedures of Hurricane Response with Concept Maps

In the previous sections, I summarized specific information from each of the concept maps created with the experts. In this section, I have collapsed and condensed that information into summary tables and descriptions. Following these summaries, I highlight the use of decision diagrams and decision ladders for developing a detailed understanding of decision making beyond the information presented on the procedural concept maps and subsequent summaries.

Key concepts that cut across maps and the decision points associated with them are included in the following section. All of the decision makers and GIS specialists discussed the utility of maps
for planning, response, and recovery activities. For the GIS specialists, as a storm approaches, activity levels were high as decision makers began requesting maps specific to the locations in the hurricane’s error cone. After this initial effort, map making often tailed off significantly until just before impact, when the exact location of the track was determined and the specific regions in harm’s way could be examined and depicted on detailed maps. Map based activities increased to their highest levels right before and in the days after impact. As GIS has been integrated into EOC activities, it has allowed maps to be used earlier in the planning stages to prepare response and recovery activities for areas where damage could occur to Hazardous Materials (HAZMAT) facilities, water supplies, special needs populations (elderly, hospitals, nursing homes). At impact and after, mapping efforts shifted to depictions of damaged regions, completed damage assessments, tracking logistical staging areas, comfort stations and mobilization site. Specifically, GIS analysts work to continuously update databases with incoming hazard related information. The need for maps after the event appears to be greater than before the event, however, GIS is helping to improve the decision makers’ access to maps and geospatial data in the pre-impact stages as well.

6.6.1 Themes and Decisions

The most important themes are those that are discussed by multiple experts. The themes I identified that spanned multiple maps are summarized below. The theme appears in bold and the key decisions and actions associated with the themes follow as bulleted lists. These themes represent the salient decision making activities during emergency response to hurricanes. Collaborative decision making technologies and geospatial information technologies to support emergency management should support these activities.

1. PLANNING AND PREPARATION
   - Conduct conference calls
   - Convene planning meetings
   - Determine protective action recommendations
   - Increase the EOC Activation Level
   - Increase agency staffing levels
   - Identify the area of operations
   - Identify vulnerable critical facilities
   - Deploy liaisons to National Hurricane Center

2. EVACUATION
   - Determine Evacuation Type
   - Discuss Evacuation Alternatives
   - Conduct Collaborative conference calls with counties
   - Notify supporting organizations
   - Increase activation level
   - Notify shelters
   - Develop evacuation plan
- Recommend evacuation of special needs populations (assisted living facilities, hospitals, mobile homes, nursing homes, keys, low lying areas)
- Consideration of lane reversals and contralane evacuations (single lane, multiple lane, full reversal)
- Recommend voluntary evacuation
- Recommend mandatory evacuation
- Recommend evacuation of waterways (intracoastal)
- Monitor evacuation
- Establish traffic control points
- Close exits and force traffic off before tropical storm force winds
- Develop evacuation plans for resultant flooding

3. SHELTERING
- Planning (preparations made in case of evacuation)
- Begins upon voluntary evacuation order
- Determine type of shelters required
- Determine number to open
- Open refuges of last resort

4. PROVISION OF RELIEF SUPPLIES
- Determine primary LSA and mobilization sites
- Determine preliminary supply orders
- Notify suppliers
- Preposition assets and commodities
- Obtain monetary damage estimates
- Prepare for a distribution system to be in place
- Identify alternative LSAs and mobilization sites
- Request Governor State of Emergency Mandate
- Request Federal assistance
- Deploy Selected Response Teams

5. DAMAGE ASSESSMENT
- Preposition damage assessment teams
- Coordination between field and EOC
- Track and reposition teams
- Identify damaged critical facilities
- Identify damaged resources and properties
- Determine dollar estimates of damage

6. RECOVERY
- Develop restoration process for Critical Infrastructure
- Assist counties in the recovery process
- Develop a temporary housing strategies
- Replenish resources and supplies

7. INFORMATION MANAGEMENT
- Receive, process, and update new information
- Distribute information to agencies and public
- Coordinate resource requests
- Establish coordinated Public Information sharing
6.6.2 Problems in Emergency Management Decision Making

Emergency managers often encounter uncertain, difficult and problematic situations that affect the decision making process. Zaff et al (1993) found that concept mapping exercises helped them to uncover problems that affected pilot performance during target acquisition; similarly, the concept mapping sessions with emergency managers identified compounding problems for decision making activities. The primary problems that emergency managers face were caused by uncertainty. Four primary sources of uncertainty were identified: uncertainty in the event, in the evacuation, in sheltering, and in the immediate impact period, each aspect of uncertainty will be discussed. Further research into these problems is required to develop potential solutions.

Hurricanes are notoriously unpredictable and exhibit a high level of event related uncertainty. Specifically, emergency management activities are affected by uncertainty about the severity of the event’s impact. Contributing factors include the storm area, storm track, storm strength, and impact timing. A problem related to the determination of impact timing includes a rapid strengthening of the storm. In such cases, the storm can stall (increasing localized rainfall amounts) causing further uncertainty in the associated hazards (e.g. rain, wind or storm surge). Uncertainty in the arrival of the storm surge (e.g. at high or low tide) also complicates decision making. Uncertainty in the position of the track relative to hydrographic features such as river systems, bays, or lakes, further increases flooding risks, requiring alternative planning. The last event related issue specific to the timing is whether the storm will arrive during the day or the night. Daytime storms allow for more rapid response while a nighttime storm delays immediate response activities significantly.

A second identified problem is uncertainty in the evacuation, and more specifically, the behavior of the evacuees and their use of shelters. Decision makers issue recommendations, but during an event cannot be sure if people have evacuated nor where the evacuees have gone. A rule of thumb one participant stated was that ‘you run from the surge and hide from the wind,’ meaning that, in general, evacuations are ordered for individuals in the storm surge flood zones, and shelters are provided for individuals outside of the surge zone that need shelter from the wind fields. That rule of thumb does not hold true for larger Category 4 and 5 storms. In those cases evacuations are not isolated to the surge zones, but expand to entire counties due to the associated wind speeds. Wind speeds in excess of 100 mph destroy mobile homes, and significantly damage other single family dwellings. These areas are ordered to evacuate based on the predicted wind speeds. Wind blown debris from the hurricane is a major factor that influences what areas to evacuate.

Decision makers must also deal with uncertainty in the ability of the road networks to handle the volume of evacuees. Further, evacuees often pull boats and RVs that might not be in road worthy condition, further bogging down the evacuation process. To help reduce strain on the road network,
evacuations are often staggered. In South Carolina, voluntary evacuations always precede mandatory evacuations, allowing time for the voluntary evacuation to ease the strain on the roadways. In South Carolina and Florida, local population and geography often dictates that the evacuations are staggered at the county level. Counties with the longest clearance time, highest population, and greatest probability of impact evacuate first, with neighboring counties further down the evacuation route following at scheduled intervals. Moreover, it is critical that the state coordinate with surrounding states to inform them of the evacuees who will be headed into their states. The ever-present question that remains unknown until the storm hits is did the decision makers allow enough time and did people listen?

The third kind of uncertainty that must be addressed is that related to sheltering. Decision makers must determine the time, type and number of shelters to open, and these figures change based on the storm’s status. The number of individuals who will require shelters during the storm event is never known, requiring decision makers to develop contingency plans. For example, if the storm slows down, it extends the amount of time people must use shelters. If the storm strengthens rapidly and speeds up, more people will require shelters because they could not evacuate. Shelters are generally categorized on the basis of the amount of damage they can withstand. If a storm strengthens rapidly and the currently opened shelters cannot handle the increased wind speeds, the sheltered population must be relocated and as shelters are filled, evacuees must be rerouted to overflow shelters. These issues are tied to whether there are motorists on the evacuation highways as the tropical storm force winds arise. Specifically, National Guard and highway patrol officers have to close off exits and order individuals to retreat to shelters of last resort. If the evacuation order was given with adequate warning, and if the evacuees heeded the advice, the roadways should be clear. However, history suggests that entropy is common when dealing with weather phenomena. A rapid increase in the hurricane’s forward speed, a swift shift in the track, or hesitation in the decision to issue the evacuation are all uncertain factors that influence the need for shelters of last resort.

Another priority in evacuation planning is provision of specialized shelters that support special needs populations (evacuees requiring specific medical attention such as oxygen, cardiac support, etc). Decision makers must estimate the composition and size of the special needs population and provide shelters accordingly. The specialized shelters are often limited, and if a storm impacts a region with a high number of special needs individuals, the ability to shelter those populations can be exceeded, requiring outside assistance. Finally, the sheltering program is altered again once the storm has made landfall. The number and type of shelters that are required post impact is dependent on the extent of damage to homes and critical facilities, such as hospitals and nursing homes.
The fourth major problem identified during concept mapping was the uncertainty associated in the storm’s immediate impact on the local infrastructure. While the storm makes landfall, responders and evacuees alike must seek shelter from the storm’s impacts. During this period, infrastructure critical to response activities can lose power and response resources can be destroyed. For example, communications networks can be destroyed, limiting the decision makers access to information required for positioning response and recovery resources in the affected regions. A Florida participant discussed this issue in detail:

“There’s a thing they call the fog of war, well there’s also a fog of emergency management situations in that, you’ll get the first calls in, and until you get some people on the ground with their eyes, you really don’t get very accurate information.”

The expert participants discussed the importance of developing technologies and strategies for getting real-time aerial or satellite imagery and data into the hands of the decision-makers and first responders. Furthermore, ensuring that the information is communicated and relayed quickly and accurately between damage assessment teams EOCs, Disaster Field Offices, and relief providers is critical to effective decision making.

Each of these four problem areas represent significant research challenges and obstacles to improving emergency management practices at levels ranging from individual first responders, to county level directors and on up to state and federal response agencies and decision makers.

6.6.3 Collaborators

The concept maps helped identify the key actors in response and recovery operations. This information provides insight into the nature of collaboration during emergencies and has the potential to assist with the development of new theories, technologies, and practices for crisis response. The people and agencies identified during the procedural concept mapping exercises are listed below.

<table>
<thead>
<tr>
<th>Federal</th>
<th>County &amp; Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>• National Weather Service</td>
<td>• EOC Directors</td>
</tr>
<tr>
<td>• Meteorologists</td>
<td>• County police</td>
</tr>
<tr>
<td>• FEMA</td>
<td>• Public Safety Director</td>
</tr>
<tr>
<td>• Hurricane Liaison Team</td>
<td>• Fire Deps.</td>
</tr>
<tr>
<td>• Red Cross</td>
<td>• Municipal Police</td>
</tr>
<tr>
<td>• National Guard</td>
<td>• County GIS Team</td>
</tr>
<tr>
<td>• RECON Team</td>
<td>• EMS</td>
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<tr>
<td>• Salvation Army</td>
<td></td>
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<tr>
<td>• US Dept Agriculture</td>
<td></td>
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<tr>
<td>• Army Corps Engineers</td>
<td></td>
</tr>
<tr>
<td>• National Highway Admin</td>
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</tbody>
</table>
### Information Requirements

The concept mapping sessions helped with the identification of the information requirements needed to support decision making in hurricane response. The mission scenario was largely focused on the immediate planning phases before impact and the response activities after impact, and thus, the information requirements have been stratified into planning related and response related bulleted lists below. Information about critical facilities was identified as particularly important for all stages of emergency management, and they are listed on the following page. As highlighted in the results discussions, critical facilities vary among county, state, and federal agencies. In the critical facilities table, all references to critical facilities from the concept maps and other interviews are merged into the table. These identified information requirements represent some of the base level database requirements for an emergency management GIS.

#### Planning Related:

<table>
<thead>
<tr>
<th>Planning Related:</th>
<th>Planning Related:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Current location</td>
<td>• Wind Swath</td>
</tr>
<tr>
<td>• Projected Track</td>
<td>• NWS Forecast Discussion</td>
</tr>
<tr>
<td>• Error Swath</td>
<td>• Forward Speed</td>
</tr>
<tr>
<td>• Cone of Impact</td>
<td>• Evacuation Clearance Times</td>
</tr>
<tr>
<td>• Strike Probabilities</td>
<td>• Potential $ Damage Est.</td>
</tr>
<tr>
<td>• Impact Point</td>
<td>• Available Resources</td>
</tr>
<tr>
<td>• Storm strength</td>
<td>• Locations of resources</td>
</tr>
<tr>
<td>• Rain potential</td>
<td>• Shelter status / strength</td>
</tr>
<tr>
<td>• Tidal Charts</td>
<td>• Road status at traffic control points</td>
</tr>
<tr>
<td></td>
<td>• Critical Facilities Infrastructure</td>
</tr>
</tbody>
</table>
Response Related:

- Intracoastal waterway
- Evacuation routes
- Roads (damaged)
- EOC locations
- Warehouses
- Disaster field offices
- Comfort stations
- Ice storage facilities
- Ice making plants
- Food storage
- Mobilization Sites
- Logistical Staging Areas
- Shelters
- Refuges of Last Resort
- Alternative Staging Areas
- Critical Facilities Infrastructure

Critical Facilities:

- assisted living facilities
- airports
- bridges
- cemeteries
- churches
- clinics
- comfort stations
- communications towers
- county buildings
- dams
- disaster field offices
- electrical power plants
- EMS stations
- Emergency Operations Centers
- evacuation bridges
- evacuation route intersections
- farms (type/size)
- fire service stations
- fire stations
- HAZMAT
- Highway Patrol
- hospitals
- hotels
- injection pumps
- kennels
- landfills (active/inactive)
- landing zones
- law enforcement offices
- marinas
- marine resources
- mass care stations
- mass transit terminals
- military bases
- mobile homes
- multi-family homes
- nuclear power plants
- nursing homes
- potable water supplies
- race horse farms
- recovery centers
- red cross facilities
- roadways road maintenance facilities
- shelters
- shelters of last resort
- single family homes
- special needs shelters
- sheriff’s department
- storage tank farms
- street center lines
- tent cities
- tourist destinations
- traffic control points
- veterinarians
- water treatment plants
- water supply regions
- well heads

6.7 Exploring Decision Making in Hurricane Response with Decision Models

Concept maps helped uncover the process of emergency management and Abstraction Hierarchies were used to identify the structure of the domain. In this section, I present models of the decisions in emergency management. One of the goals of the CTA was to identify the nature of
decision making activities and, specifically, the key decision points around which actions are undertaken in hurricane response.

I created the decision making diagram below (figure 6.27) based on the concept map from the South Carolina Hurricane Program Manager. The color scheme used to represent each OPCON level coincides with the Department of Homeland Security color scheme that designates heightened vigilance to potential threats. The diagram is organized by OPCON level, and depicts the most important decisions that are made prior to landfall of a hurricane.

![Diagram of decision making process](image)

**Figure 6.27 SC EMD Decision Making Summary**

During concept mapping, the program manager discussed five major periods of activity: monitoring, organization and build up, decision and active preparation, evacuation and post impact. These phases line up with the decisions to elevate the OPCON levels of the Emergency Management Division. The stars represent key decisions that were identified as driving forces for activities at the state level. Because jobs and tasks are directly linked to OPCON levels, the decision to increase OPCON levels drives the initial stages of the response effort. As the storm nears the coastal margin, the decisions shift to specific details of the evacuation decisions. When a voluntary evacuation is issued, the entire division is raised to OPCON 1. The mandatory evacuation follows the voluntary depending upon the spatial and temporal proximity of the storm. Information sources that are imperative to making each decision as time progresses appear at the bottom of the diagram.
For Florida, a different model of the decision making activities was produced based on the information elicited during the onsite visits. Instead of the driving forces being the OPCON level changes that designate the division’s collective and individual activities, information collected in Florida focused on an iterative decision making cycle (see Figure 6.28). Every decision to begin a new process during emergency response (evacuations, sheltering, resource positioning) creates a new need for information and subsequently initiates a new decision making process. Information required to make the decisions comes in the form of reports (statistics about the likely expense and cost of the storm in terms of dollar damage and destruction of buildings), maps and imagery of the incoming storm, and data layers of critical facilities, threatened infrastructure and vulnerable populations. With each decision, a new process is initiated that has its own set of information requirements (monitoring, sheltering special needs populations, repositioning resources, increasing resource requests, etc). This entire process continues on in a similar fashion until the emergency response team is no longer actively supporting, acting and directing the response and recovery efforts.

Figure 6.28: A representation of decision making in Florida’s hurricane response

The previous diagrams are high level representations of decision making activities in emergency response. In the following paragraphs I highlight the use of decision ladders as a mechanism for developing a deeper understanding of the decision making activities and their
relationship to tasks and actions in a work domain. An important decision making activity in hurricane response is the decision to evacuate. That decision initiates a host of other activities related to emergency response. Decision ladders provide a structure on which to model the information processing activities and actions associated with a specific decision. Arrows indicate the movement of information processing activities through the ladder. A decision ladder can help develop an understanding of the role of tacit knowledge and expertise in decision making. For example, when decision makers use their expertise, they do not traverse the entire decision ladder, and instead move directly to execution of tasks through cognitive leaps across the ladder (from the left side to the right side and indicated by the bold arrows). The following four diagrams are associated with specific prompts (outlined below) from the Hurricane Wilma mission scenario. To develop a deeper understanding of the use of geospatial information and technology in hurricane evacuation and to illustrate the potential of decision ladders as a tool for understanding crisis management more generally, I developed four decision ladders. Each is focused on a different specific prompt from the Hurricane Wilma mission scenario.

The decision ladder contains square boxes (information processing activities) and circles (states of knowledge) that were developed by Rasmussen (discussed previously in Chapter 2). Moving up the left side of a decision ladder, the focus is on considering options based on an initial activation item that begins the decision making process. Moving down the right side of the ladder, the processes are moving toward execution of a specific task or procedure that was initiated by the activation item. In figure 6.29, at 72 hours before landfall, the National Hurricane Center issues an advisory. That advisory is the activation of decision making activities for the Florida SERT. The bold arrows indicate the movement of decision making activities by emergency managers for that specific temporal period.

On the decision ladder, the observation and questions that the decision makers indicated they examine are represented in blue boxes. In this first situation, the decision makers observe that the storm is only a Category 0, and begin to assess options. Given that there is so much ambiguity and uncertainty associated with the current storm, the SERT decision makers conduct planning meetings, brainstorm hypothetical situations, and ultimately, raise the activation level of the EOC. However, given the high degree of uncertainty, they decide that no further action is needed. At this stage, the decision making process did not traverse the entire decision ladder. Instead, the decision makers use their past knowledge of similar situations to interpret the situation, and immediately proceeded to take action (meetings, raise status, etc).
Figure 6.29 72 Hour Decision Ladder
Figure 6.30 48 Hour Decision Ladder
The next decision ladder examines the decision making activities at 48 hours before landfall of the storm. In this instance, the driving force initiating the decision making process is that the storm has entered the Florida Straits. Even though there was still considerable uncertainty associated with the storm’s strength and ultimate point of landfall, decision makers indicated that the short time window and the likelihood of damage to the fragile populations on the Keys would prompt immediate action. During the onsite visits, the decision makers indicated that based on past experience with storms in the Florida straits, the SERT team would increase the activation level of the EOC to Level I and begin evacuations of special needs populations in the Keys by air medivac. They would also begin to prepare supply orders to support the recovery operations. In this decision ladder, the role of past experience of the collaborative group of decision makers prompted an expert based leap from the identification of a threat to the execution of tasks.

At 33 hours out (Figure 6.31), the NHC issues a hurricane watch. A hurricane watch means hurricane conditions are likely in the next 24-36 hours for the watch area. The moment the watch is issued, the decision makers indicated that they would need to immediately calculate an estimate of the number of people requiring evacuation. Based on the identified total (and the current projection of the hurricane’s speed and landfall and individual county evacuation clearance times) the decision makers would determine the appropriate time to issue voluntary and mandatory evacuations. Given the information based on the current storm, the decision makers indicated that they would recommend a voluntary evacuation for the threatened population. Most important was an evacuation of special needs populations because of the length of time and resources required to evacuate those individuals.
33 Hours Out

Figure 6.31: 33 Hour Decision Ladder
The final decision ladder (Figure 6.32) represents the decision making activities at 21 hours out. The NHC has issued a hurricane warning indicating the storm is a significant and immediate threat. The decision makers know that a warning means ‘it’s the real deal’ requiring immediate action. Given this information, an immediate decision to recommend mandatory evacuations would be ordered. Final preparations for the storm event (determination of area of operations, finalization of supply orders, open shelters of last resort and repositioning of resources) would be made to support rapid response and recovery operations.

The decision ladder representations suggest that in time critical situations, such as emergencies where lives and property are at stake, there is limited time for extensive negotiations and examination of all possible outcomes. In actual events, the unpredictability of the storm greatly compresses the window of time the decision makers have to act. The decision makers have trained and drilled for these activities, and upon seeing specific inputs (such as the location of the storm in the Florida Straits or the NHC hurricane watches and warnings) they tap tacit knowledge and past experience to make associative leaps through a decision making process, and move directly into action and execution of the appropriate, often pre-identified tasks. During planning and brainstorming exercises, each element on the ladder might be traversed (sometimes several times). During actual events, high stakes, ill-defined situations and time critical tasks prompt decision makers to rely on heuristics and short-cuts from information processing prompts to action (thus, associative leaps across the ladder).

In the context of emergency management, tacit knowledge, past experience as well as predetermined guidelines and tested procedures likely prompt shortcuts to action and execution. The decision ladder is a mechanism that can help researchers identify the specific events, guidelines or expert knowledge that prompts the associative leaps to action. I used the decision ladder template as a mechanism to explore decision making activities based on information collected during the onsite visits. The decision ladder template seems even more appropriate as a data capture mechanism during both direct observational studies of emergency management activities and as a template to prompt knowledge elicitation in a participatory format with experts (in contrast to summarizing and modeling collected information on the framework).
Figure 6.32: 21 Hour Decision Ladder
6.8 Summary and Conclusions

This chapter has highlighted the results from several representations and models that have helped develop an understanding of work with geospatial information in hurricanes. This information indicates that there is a need to make GIS easier to use and to develop enabling, collaborative technologies to support the work of teams with geospatial info.

The decision makers indicated that they are reliant on geospatial information to improve situational awareness, resource allocation, and to make informed decisions. While most of the decision makers had taken training courses in GIS in the past, they indicated that it was difficult to remember how to use the software and that, during emergencies, they did not have time to sit down in front of the computer and figure out which operations they needed to perform to display the data. To overcome the difficulty in interacting with GIS, the emergency managers channel geospatial information and mapping requests through GIS specialists, who create the required maps on a case by case basis. The GIS specialists identified that much of the information being requested was only needed for short term use, and were thus, developing methods to improve and simplify the GIS interfaces and electronic, large screen display of the information, thus increasing the responders and managers access to geospatial information.

More advanced map interfaces were also highly desirable in the EOC. Large screen map displays depicting traffic patterns and densities, resource tracking and display, and queries by population, structure type, and region were described as technologies that would improve the efficiency of emergency management activities. Currently, information was being tracked on paper lists and printed maps; dynamically shared maps were a recognized addition that the decision makers desire.

The DAVE_G project has a goal of developing a dialogue-based system that anticipates the needs of the individual users of geospatial information. The concept maps contain the specific information requests of individual emergency managers. These information requirements can be built into individual profiles for specific experts, groups of experts, divisions, and even emergency events. When the expert initiates the program, the information requests of that individual’s past interactions in a similar situation can be preloaded, yielding a predictive mixed initiative system that is responsive to the expert’s needs. Since individual experts would generally complete the same tasks (regardless of the emergency – though some disaster specific situations exist as well), the intelligent system would not need to be hurricane specific (for example, the Operations chief is going to need to know how many people need relief supplies, distribute those materials, and track the available resources) for any disaster, whether it is a hurricane, wildfire, or flood. This approach is also ideal because
emergency management tends to have a high turnover rate, thus, the previous managers expertise can be encoded, and institutional memory can be preserved and passed to the decision maker’s successor.

The concept mapping sessions highlighted the intricacies of collaborative activities during emergency response. A majority of the pre-impact decision making activities at the state level indicate that collaborative geospatial information technologies need to support groups of 5-15 decision makers congregated in planning rooms. During these planning meetings in both state EOCs, several counties join the teleconference (in Florida, in excess of 50 county emergency managers and even the entire operations center can be listening and participating in the conference meetings). Federal liaisons at the National Hurricane Center and at FEMA regional headquarters often participate in these planning meetings as well. The emergency managers often coordinate with teams deployed in advance of impact. These teams manage mobile command sites, distribution sites, logistical staging areas, and other relief supply activities. Connected both to the mobile command posts and the EOC are rapid impact assessment teams. These teams must communicate geospatial information witnessed on the ground back to the EOC. The EOC also receives hundreds of reports of damage from counties and other local officials, these reports must then be communicated back to the damage assessment teams. The amount of information that must be communicated between emergency operations centers, field teams, and first responders is extensive. Often, during the immediate response, communications networks are damaged, thus, the teams distributed in the field need to be able to identify the locations of damaged areas, save the identified coordinates, and then relay that information back to the EOC when communications are reestablished. Advanced geospatial information technologies should consider mechanisms to support the issues of collaborative communication highlighted here.

This chapter has also highlighted the utility of three representation methods for modeling work. The procedural concept maps provided detailed information about the process of emergency management. They helped uncover specific information related to the individuals involved in hurricane response. Specifically, they identified the decision makers and their specific activities. They also uncovered the process of map production and dissemination of geospatial information activities in supporting decision making. The information requirements needed for effective decision making situations were also identified and summarized.

Abstraction Hierarchies were used to develop high level models that identify primary goals and physical entities that meet those goals during emergency planning and preparedness, response and recovery and mitigation of hurricanes. It was easiest to identify the highest level goals in emergency management and place them on the abstraction hierarchy. Similarly, the physical entities (first responders, disaster assessment teams, etc) that carry out those activities during crises
were also relatively easy to identify and place within the hierarchy. Emergency response occurs primarily at the local level. However, supporting entities such as ESFs and relief organizations are often at the core of emergency response activities. The emergency management domain has a deep organizational structure within and among the ESFs and other entities that coordinate and respond to emergencies. The physical components of each of those entities (such as ESFs) often vary across states, and are not easily identified and represented with the framework of the abstraction hierarchy. Moreover, emergency management is extremely complicated in the interaction and cooperation between and among states and counties, and the relationships change in an evolutionary fashion. Research focusing on the composition of the ESFs, their duties, and the composition of the teams is needed to further expand and develop the hierarchy to improve understanding of the domain of emergency management. Efforts to expand, refine, redefine and develop new hierarchies have the potential to expand the understanding of the functional activities of emergency response and the physical tools needed for its instantiation.

Concept maps are abstract representations of work in context. As such, they are one means of capturing the chaotic nature of work activities in time critical decision making environments where the stakes are high and the uncertainties are extreme. Concept mapping sessions driven by a mission scenario yielded a large volume of useful information about the processes, decisions, information requirements, events, and activities of hurricane response activities. Through the process of formalizing the concept maps, I identified and created high level categories of decision making activities specific to hurricane response (planning and preparation, evacuation, sheltering, provision of relief supplies, damage assessment, and information management) that can serve as foci for future research. I identified important decisions within each of those categories as well as the information requirements and individuals involved in completing the related activities. Further, I applied a color coding to the formal concept maps to help produce summaries of the specific actors, decisions, problems and information requirements in emergency management.

The decision ladders represent detailed examinations of the collective decision making activities of the Florida SERT division during hurricane evacuations. These representations provide insight into how external events drive the information processing elements of decision making activates during emergency response. These ladders help ‘drill down’ to the details of specific inputs and constraints on decision making activities. The ladders also help identify the external factors and elements of expertise that prompt associative leaps from observations of phenomena to task execution. Future research focused on the information processing and decision making activities of individuals has the potential to iteratively develop a deeper understanding of decision making in the context of emergency management.
The breadth and depth of information presented in this chapter demonstrates how multiple representation techniques can be utilized to represent a work domain, the individuals working within the organizations, the specific decision makers and the individual decisions.

There were some challenges encountered in my experience with concept maps. First, the number of nodes and links that appear on the procedural concept maps can make them difficult to read. One expert commented during validation that it was difficult to understand the map. However, this expert validated the information electronically in an onscreen display instead of the paper maps mailed to the other emergency managers. The 60 inch long virtual document of the procedural concept map does not lend itself well to onscreen display and analysis. Once the same expert had taken 10 minutes to review the map, he indicated that, in fact, it did represent the information accurately, capturing some of the difficult issues (uncertainty in the storm, need for preliminary damage estimates) involved in the Hurricane Wilma event specifically and in hurricane management more generally.

Second, the fixed timeline on the concept map has limitations. Specifically, the time line suggests that the time is absolute, and that activities occur at the specific points in time at which their labels appear on the concept map. Most of the information elicited during concept mapping sessions included some aspect of uncertainty, and was driven more by events than by specific temporal cues. The time line is the anchor on which events are related in succession, but the explicit, linear representation itself limited flexibility during concept mapping sessions. The rigidity of the timeline and the implied metaphor of time being linear and continuous does not completely represent highly uncertain, event driven process of emergency management. Fixed linear timelines, while useful in this research, seem more appropriate for shorter duration events with specific orders of actions. For example, target acquisition by pilots (as discussed in Zaff et al. 1993) is a short duration event, and thus, lends itself well to such a representation. The timeline might also be an appropriate method for post-hoc representations of observed actions that are assigned specific timestamps. For tasks with much longer temporal dimensions, an event based approach seems more appropriate.

A third problematic issue encountered during concept mapping was that the mission scenarios were only hypothetical situations. Because of the lack of more concrete information, the participants answered with hypothetical or historical situations. One possible way to overcome this issue would be to create more detailed mission scenarios prior to knowledge elicitation from individuals in the team. The specific mission scenarios could include more detailed situations such as, “the EOC manager requests a map of X area showing Y information. How do you proceed?” Another potential variant would be to have all of the individual decision makers collaboratively discuss what specific information they would request given that situation.
In conclusion, the abstraction hierarchy, procedural concept map, and decision making models and representations were useful in uncovering information related to the structure, procedures and decisions in emergency response. Beyond the information reported in this chapter that contributes to the development of a deeper understanding of crisis management, the experiences reported here highlight known deficiencies in studying work outside of actual context. However, since access to emergency managers during actual events is, and will likely remain limited, more extensive study of these types of knowledge elicitation and representation methods with teams of experts is needed to further improve the utility of such field work.
Chapter VII:
Scenarios & Scripts for Building Scaled Worlds

One must learn by doing the thing;
for though you think you know it,
you have no certainty, until you try.
-- Sophocles --
7.1 Introduction

This work has the potential to improve our understanding of GIS use in crisis management and to extend that information to inform multiple domains including the development of common ontologies of crises, common ways to visualize and utilize those ontologies, the development of better interfaces to find and acquire useful imagery, methods to deal with event related uncertainty, improvements to collaborative concept mapping knowledge elicitation techniques. It also can inform methods for representing knowledge in ways that promote its sharing among researchers and experts as a basis for preservation of institutional memory, educational programs, and the role of transactive memory in time critical crisis situations. Of these issues, this chapter focuses on one application of the information, specifically to the design of scenarios to improve the design development of the DAVE_G prototype.

First, I present a brief review of scenarios and their role in understanding work and building technology. Next, I highlight the iterative development of scenarios for the DAVE_G project. Finally, building on the lessons learned from the initial scenario development, I present two types of scenarios, summary scenarios and script scenarios, and discuss how knowledge elicitation activities inform scenario writing for both. Specifically, I present summary scenarios as a mechanism for structuring the elicited knowledge, or ‘raw material’ on which to build more detailed script scenarios. This work relates to the living lab approach to CSE in that the scenarios, as they are presented here, form a basis for building scaled worlds and iterative prototypes. The script scenarios, taken alone, are a conceptual representation of a scaled world.

One measure of the usefulness of Cognitive Task Analysis (CTA) is its ability to yield envisioned designs. In the past chapters, I have provided detailed investigations into individual components of work in emergency management. In this chapter, I integrate the information collected during the offsite and onsite activities into scenarios of work in emergency management. These scenarios are presented in several ways. Generally, the scenarios are presented as combinations of text and visual images to illustrate a specific emergency management situation. Such scenarios serve as a model of work in emergency management (concept maps, abstraction hierarchies, summary tables and decision ladders are other models). These models, taken collectively, are a means for communicating knowledge elicited during a Cognitive Task Analysis to other hazard researchers, technology developers, and other interested persons.

This chapter also discusses the process of scenario development and the different manifestations those scenarios can assume. Lessons learned in the development of scenarios for the multimodal gesture-speech DAVE_G mapping system are discussed. The process of merging elicited knowledge into scenarios is also highlighted. The scenarios developed for DAVE_G recreate
decision making activities during hurricane response with specific attention paid to the role of
deeospatial information technology. They provide general insight into the activities of hurricane
response and are thus important for improving our understanding of work in emergency
management. This research, however, specifically explores their utility in the development of
multimodal geospatial information technologies. The scenarios developed initially for the DAVE_G
project evolved into a format presented at the end of the chapter, summary scenarios and script
scenarios.

7.2 Background on Scenarios

Scenarios have likely been around for nearly as long as human thought. The term scenario is
used in a range of contexts and can be easily misunderstood. At their heart, scenarios tell stories,
and thus literature and plays represent some of the oldest examples of scenarios. A scenario can be
written in the past, present or future. Formal applications of scenario based, futuristic planning
originated in competitive business practices. Fahey and Randall (1997), Ringland (1998) and Swartz
(1991) provide three different accounts of the history of scenario design in strategic business decision
making. Specifically, they discuss the original work conducted by Herman Kahn for the US Military
during the 1950s at the RAND Corporation, followed by the shift in the 1970s to Royal Dutch/Shell
and the Stanford Research Institute (SRI) International. The work with scenarios at Shell is generally
recognized as the most widespread use of futuristic scenario planning in the corporate world. Swartz
(1991) summarizes the scenarios generated there, drawing attention to the prediction of the formation
of OPEC and the resulting oil price fixing. Fahey and Randall (1997) outline the continuing
advancement of scenario design by prominent consulting corporations in the following decades (e.g.
Despite the widespread use of scenario planning and decision making in businesses, little attention
has focused on how scenarios are created and represented; an exception is Swartz (1991). Swartz’s
initial work with SRI International eventually merged into consulting and collaboration with Shell.
collecting and observing information in order to write scenarios useful for futuristic thinking.

While scenario planning suffered a decline in use within strategic business planning circles in
the late 1980s and early 1990s, their utility in HCI and software engineering gained popularity in the
1990s (Ringland, 1998). Kuutti, (1995) points out that scenarios did not have strong roots in HCI or
software engineering and emerged as an important tool for software design within a 10 year time
frame. She noted that most advocates of scenarios as a tool for software development tend to take
them as “given.” She also recognizes that despite the widespread use of the term and their growing
popularity, there was no agreement on the definition of a scenario. See Kuutti (1995) for an overview
of other attempts to define scenarios and a discussion of their emergence in HCI and software engineering communities. In CSE, McNeese et al. 1990 and Zaff et al. 1993 developed an integrated approach to developing scenarios based on the integration of elicited knowledge collected from pilots via IDEF-0, concept mapping and design storyboarding. Such a comprehensive approach represents the aim of much work in HCI and CSE today.

In an edited book about scenarios and their use in HCI (Carroll, 1995), several of contributing authors discuss how a scenario based approach can help a collaborative interdisciplinary team communicate with one another to make better design choices. The role of the scenario throughout the design process is discussed in detail. What the authors do not provide are detailed descriptions or examples of scenarios. Wright (1992) suggests that a scenario is an episode, or a situation with a temporal component; Nardi (1992) defines a scenario as a description of an activity, in narrative form. Carroll (1995), while generally advocating text narratives, suggests that scenarios do not have to be text narratives, but could be storyboards of annotated cartoon panels, video mockups, scripted prototypes, or physical situations representing user activities. Key points, he suggests are that there are multiple levels of description and detail, and the defining property is that the scenario provides a concrete description of a user’s activities while performing specific tasks. Such descriptions, according to Carroll (1995) need sufficient detail so that designers can make inferences about the nature of the interface design.

To date, HCI continues to lack a coherent methodological approach that defines scenario types, scenario writing, or appropriate scenario use. Moreover, the level of detail a scenario should comprise and when they should be used in system design is largely unclear. Carroll (1995; 2001; 2003) and Rossen and Carroll (2002) are the most prominent champions of scenarios as envisioned designs for technology, however much of the discussion provided on scenarios is cast in simple, minimalist tasks such as inserting images into a word processing document. Moreover, the argument often maintained is that formal approaches to scenarios are not necessary, as a scenario should be highly adaptive, accessible to all interested parties, and constantly challenged. While an informal approach might yield positive results for experts who have worked with and designed scenarios for several years and have access to designers familiar with scenario based design, it does little to assist the novice interested in building and developing scenarios of use for system design or for the creation of envisioned, future technologies.

In comparing the scenario planning of the business community with that of the HCI community, a scenario developed for strategic business decisions often covers a large span of years and multiple players (e.g. governments, businesses, etc) in an attempt to predict future business practices within a changing global economic climate. These scenarios are extremely broad in scope
and vision. On the other hand, scenarios in HCI tend to focus on usability aspects of existing computer programs in order to better refine and develop the interfaces and software packages. Within these two end points of scenario types, from the global to the local (or minimalist), exists a range of ways to describe and communicate information about work via scenarios that has yet to be explored, categorized, and defined.

In the business community, van Notten, et al (2003) created a typology of different kinds of futuristic scenarios. Specifically, they created a scenario cartwheel that classifies developed scenarios according to whether they are formal or intuitive, simple or complex, and designed for exploration or decision support. A similar attempt could provide a useful foundation for scenario development in information technology. Specifically, by creating matrices, continuums, and other representations of different types of scenarios, with specific attention to appropriate applications of them in a field of practice, proponents of scenarios could further expand and explore the utility and appropriate use of scenarios in design. Moreover, such an approach would make it easier for scientists or software developers from outside the field to develop and use scenarios within their own domains.

Van Notten et al (2003) provide a useful starting point for examining types of scenarios, however I believe a scenario typology needs to have a space-time dimension. In Figure 7.1, the issue of scale from the global to the local is introduced. The diagram attempts to link different types of ‘scenarios’ (on the bottom) with applications of scenario use (the top) in a range from the global, futuristic scenarios (with temporal spans of several years) developed in the business community to local scenarios of computer use (with a temporal span of a few minutes) more common in usability and HCI circles. The top label, ‘envisioned futures’ refers to anything that has yet to be developed, whether it is a new database being designed by a software engineering company (on the left side) or a new world alliance that alters global trading and political alliances (on the right side). A scenario can be developed to describe the functional operation of the database to support a development team. Similarly, a fictional story can be written that predicts a new world alliance, describing the implications and issues in this new, envisioned future. The format of each of these ‘scenarios’ would need to be extremely different. I have attempted to characterize some of the middle ground in this continuum to examine the types of scenarios appropriate for a particular situation. For example, a simple text narrative might be appropriate to initiate design of a new interface, but might not be an adequate in scope to describe a national research agenda, and instead a book or an NRC report would be a more appropriate ‘scenario.’ NRC reports, the business community and government often create envisioned ‘future worlds’ with scenarios of changes in global economics and politics. Figure 7.1 is a preliminary diagram and could benefit from expansion and development of the categories of
problems (e.g. social, technological, political, etc) and the context of those situations (decision making, brainstorming, design, etc).

Figure 7.1 Scenarios and Futures

One way to parse the types of scenarios on the bottom half of the diagram would be to categorize them based on the affordances, or visual and textual descriptions that a given type of scenario provides the users. For example, if the challenge is to think of new hardware technologies that might be used in emergency management in 10 years, then the appropriate scenarios might include envisioned video demos, fictional stories, or even science-fiction based narratives that provide visual and textual descriptions of the future technology. On the other hand, if the goal is to refine an existing web based interface, an appropriate scenario might be a comprehensive list of the actions and commands that pools of users would perform.

A second parsing of scenario appropriateness involves a division by routine or non-routine events. Routine events would involve the day to day activities one might perform at work. On the other hand, a routine event in hurricane response might be the creation of planning maps prior to landfall of the hurricane. While the use of the term routine might be a bit misleading in this case, the degree to which something is routine is context dependent and highly variable. While hurricanes are not ‘routine’ events per say, in the event that a hurricane track indicates it will hit a specific region, the typical or routine activities that emergency managers perform would represent the first areas of
focus for developing advanced technologies that would augment their work practices. Once the system was able to support the routine cases, the envisioned designs can be expanded by the creation of scenarios focused on events that were non-routine, emerging, and rapidly changing (such as rapid strengthening of a storm, sudden changes in storm track, stalling and increased flooding, power loss, etc). Thus, in reflecting on figure 7.1, the terms local and global could potentially be swapped with routine and non-routine, respectively. Alternatively, they could represent separate, albeit related dimensions. The futuristic envisioned scenarios on the right side of the diagram would be abstractions of a world full of unknowns and uncertainties, and those at the left side of the diagram would be focused on the concrete situations that systems and tools must support.

All scenarios have temporal elements. The written scenario can depict activities with short durations (launch an application and save the file) or much longer periods of work (over hours, weeks, months, years or decades). For each temporal type, one scenario format might be more appropriate than another. For example, a movie or a novel might best communicate scenarios that represent activities that occur across years and a simple script or list of actions might be more appropriate for activities requiring an hour or less. To date, there is no clear system for matching the appropriateness of scenario types with the work they represent. The categorization of scenarios and a system for matching scenario types with appropriate tasks and envisioned futures is open for exploration.

7.3 Lessons learned from scenario development for DAVE_G

The iterative development of scenarios and technology for the DAVE_G project is highlighted in the following section. The scenarios written for the DAVE_G prototypes would fall just left of the middle of the continuum in figure 7.1. In general, they are descriptions of situations and the specific actions and commands that emergency managers might use when interacting with a gesture-speech enabled GIS. Some of the scenarios also describe a dialogue between the user and the computer, and thus contain some preliminary elements of scripts. The following section discusses the process of integrating elicited knowledge into scenarios as a mechanism for designing the DAVE_G prototypes. Several examples of the initial scenarios are presented.

To ensure that scenarios are realistic depictions of work and activities, scenario writers need a base level of expertise within the domain. To achieve this goal, knowledge elicitation activities conducted with experts are a useful means for developing the knowledge of the domain. In this research, individual elements of the CTA provided the inputs from which the scenarios presented in this chapter were constructed. Specifically, each portion of the CTA provided elements of the information required for scenario creation.
Offsite work (including bootstrapping, artifact collection and informal conversation) was necessary to focus scenario development on hurricane response. It helped to identify appropriate field sites to study emergency management decision making during hurricanes. The offsite work also helped with the identification of basic GIS support requirements during emergencies, which influenced the design of mission scenarios (the scenarios used to anchor procedural concept mapping sessions).

The onsite work was especially critical to scenario writing. It provided opportunities to witness the process of map making in emergency management, including detailed information about the numerous software packages used to present charts and maps to support decision making activities. The hurricane plans for individual states provided critical information about the planned activities, and the timing of actions and decisions as the hurricane event unfolds. Emergency management plans were useful for structuring the plots and individual sub-scenes for scenario writing.

The onsite fieldwork uncovered answers to questions about the use of geospatial information in emergency management. Recall that a multitude of mapping technologies and map types are used to support emergency management decision making. The scenarios developed for DAVE_G focused only on the maps created with existing GIS technologies. An initial step in writing the scenarios was to identify the specific mapping tasks required to produce maps for decision support. Recall that most of the maps created during emergency response activities required only the simplest GIS operations performed on multiple information layers in a large database. Specific GIS operations that specialists use to produce maps for decision makers during hurricane emergencies identified in Chapters 4, 5 and 6 were: display / add / remove layers, clip / merge, show attribute table, create new layer, edit features, contouring, rubber-sheet imagery, change symbology, highlight feature, point in polygon query, create new shape file, update data base, query by attribute, obtain information about point or polygon data, obtain summary information about points and polygons and buffer points, lines and polygons.

It was also important to identify the needed data support. The information requirements and critical facilities identified in Chapter 6 represent the baseline database content for an emergency management GIS. Because the project goal was not to build a database to support all possible queries of critical facilities and infrastructure layers, the requests were abstracted to a smaller subset of generic, routine tasks that require only a limited number of datasets.

The procedural concept mapping sessions anchored by mission scenarios with multiple individuals helped to identify cooperative and collaborative activities. The concept maps were also
helpful in the identification of sub scenes and sub plots in hurricane management specifically and
also served as a prompt for discussions related to other emergency and crisis situations as well.

From the master plot represented by the mission scenario, sub scenes related to specific
decisions and events were extracted from the procedural concept maps. These subplots are often tied
to the specific decisions for that given period (e.g. evacuation, evacuation timing, lane reversals,
resource deployment, damage assessment activities, etc). Also within each scene, the concept maps
assist in the identification of the actors and key players during the process. For example, figure 7.2
depicts specific instances where key decision makers were identified for a given decision making
time frame.

Critical incident probes and recollection of past events are crucial for scenario writing. They
provide historic scenes that can be used to build scenarios as well as the explicit dialogue among
collaborators, including the information requests of decision makers during emergencies. Two
specific examples of dialogue collected in South Carolina that were not included explicitly in the
following scenarios are presented below:

DEcision MAKer: “I need a map of the impact area showing the urban
boundaries, and the water treatment plants, and the roads.”
MAP MAKer: “Do you need all the roads? Major roads? Interstates?
State Highways?”
DEcision MAKer: “Will you make me a map showing all of the elderly
population in this area?”
MAP MAKer: “Would you define elderly please?”

Other specific quotes from decision makers include:

‘I need a map of all the mobile home parks in this area.’
‘Show me the tornado path’
‘Where is there standing water right now?’

Figure 7.2: Actors extracted from two concept maps
‘Show me all of the power lines that are down across the streets.’
‘Show the parcel layer. Show me all parcels that are greater than 1 acre and less than 5 acres with a zoning of FA, and a building of greater than 2,000 square feet on it.’

The elicitation sessions also helped to identify the most important decisions during hurricane response. These decisions can help determine the specific focus of system development. For example, the most important decision related to hurricane response identified during the CTA was the decision to evacuate. As one participant noted,

“Primarily, the whole question before landfall is: Who are we going to evacuate? When are we going to evacuate? And once we do that, what are we going to do? … So it’s really pretty much an evacuation ball game and a sheltering ballgame…the information that we would want, once we start that evacuation, is ‘What is the shelter capacity of various counties or what is the shelter status of various counties?’”

These specific descriptions provide the necessary detail for filling in and constructing a script for scenarios.

For effective, long term system development and refinement through participatory design, first generation systems (like DAVE_G) need to first support the basic, routine activities of emergency management. Once these functions are supported, experts can use the prototype system and suggest refinements and modifications for next generation systems. Moreover, if the system supports generic and routine commands (thus, being useful for all emergencies), the prototype would be more robust, expanding its utility and increasing the likelihood that experts would interact with the system to help refine the design. With those priorities and goals in mind, initial scenarios were developed to support such routine functionalities. While the specific commands or requests indicate information specific to a hurricane, subtle changes in the wording could support other emergencies. Several emergency managers indicated that a typical request they would make during a hurricane event would be:

“Display all of the shelters in the storm surge flood zone.”

If the scenario were changed to firefighting, the request might be:

“Display all of the distribution stations in the fire zone.”

Either way, the statement follows a standard format, and thus is not “event” specific. Moreover, by supporting generic functionalities, such a system would not even be tied to just emergency management support, but could be extended to other command and control applications and decision making activities supported by geospatial information.

A high-level, distinction can be made between kinds of requests that decision makers would make. Some are of the sort: Action (directed at display) → thing (in the world, typically visible on or potentially visible on the display – and encoded in the GIS database) → qualification (perhaps spatial,
perhaps not). These are not specific to emergency management. If the “thing” is a geographic scale feature and the “qualification” is spatial, then these are specific to geospatial display. Other requests involve situations in which the “Action” was intended to apply to the world (as in: start the evacuation of the Parson’s subdivision). In this case, the action may be specific to the problem context and only interpretable in that context. The following statements (a travel or wayfinding and an intelligence analysis example) emphasize how context affects the interpretation of the command:

“Show all the restaurants in the downtown.”

“Let me see the uranium enrichment factories in North Korea”

Moreover the variations within what was requested could also expand significantly (e.g. display, show all, let me see) and would vary by individual, regional dialect, domain, etc. Thus, in order to get a prototype system that experts could interact with, a small set of support operations was identified. To help identify the underlying issues related to system support, the simple commands related above are broken down into their key elements in the following text box discussion. This characterization was developed to provide a high level overview of the fundamental support needed in DAVE_G. The information assumes that the person making the requests is interacting naturally with a GIS analyst, or in the cases of the DAVE_G project, interacting with the gesture speech enabled GIS.
The primary information requested by emergency managers follows a basic structure with three elements:

OPERATIONS
OBJECTS
QUALIFIER (location, attribute, time).

For example, the command:
"Show me all of the critical facilities in these three counties."

OPERATION  = (“Show me” == display a layer)
OBJECT     = (“critical facilities” == layer to be displayed)
QUALIFIER  = (“these three counties” + gesture component == spatial extent of features to display)

For spoken commands and requests, the order might change, but the basic elements (e.g. Operation, Object, and Qualifier) would not change. Therefore, a user could say:

“I think the storm is going to impact this region; I need to see the critical facilities there.”

QUALIFIER  = ((“this region” + gesture component) || (“there” + gesture component == spatial extent of features to display))
OPERATION  = (“I need to see” == display a layer)
OBJECT     = (“critical facilities” == layer to be displayed)

Initial work by the DAVE_G design team focused on developing a prototype that supported such simple GIS commands (zoom, pan, and the display of individual layers). Upon completion of the onsite visits, elicited knowledge was used to create initial scenarios that used these simple commands in the context of hurricane response. As one member of an interdisciplinary team of developers, I developed the following scenarios to help guide system development based on the information about work activities uncovered during the CTA. These scenarios provided a vehicle for presenting key, real-world examples of geospatial information and technology use in a format that supported research on GIS support, natural language processing, vision tracking, dialogue management, and interface design for a gesture speech enabled mapping system. In this section, the creation and evolution of these preliminary scenarios is documented and discussed.

A series of scenarios developed for the DAVE_G project based on information collected during the CTA were built on the operation, object and qualifier structure presented above. Most of the initial scenarios were command oriented, with the emergency manager dictating what the system should display. As the project continued, project team members requested examples of dialogue between the emergency manager and the system. To support the dialogue portion, the scenarios focused on the specific text of individual commands with a few accompanying images to highlight the action. The scenarios developed are representations of how the emergency managers expressed
their current communication process for requesting geospatial information from GIS specialists, and thus have a strong verbal component.

7.3.1 DAVE_G Scenario #1: Supporting Routine Geospatial Information Queries

The first scenario is a simple decision support description of routine events. It was developed to support basic operations that emergency managers indicated as important: indication of spatial location, display of important information, point in polygon query, and attribute information query. This scenario represents an initial envisioned design for a multimodal system for crisis response, and describes specific actions and variations of information requests that emergency managers indicated as important to hurricane planning. An important note is that the term, critical facility, was used as a generic place holder. There are many kinds of critical facilities and emergency managers indicated that they would typically request information specific to one or two critical facility types (shelter, hospital, EOC, etc) given their specific task (rather than ask about critical facilities generally). However, the speech processing features and database support of the DAVE_G prototype required a simplified vocabulary with only a few select terms, preventing the inclusion of all critical facilities. Nevertheless, the critical facility term could be replaced with any of the examples listed in Chapter 6.
SCENARIO # 1

On screen is a base map of the southeastern US with the following layers: state boundaries, rivers, and county boundaries.

INDICATION OF SPATIAL LOCATION AND INFORMATION DISPLAY

SPOKEN COMMAND:
"Show me all of the critical facilities in these three counties."

VARIATIONS:
"I think the storm is going to hit this region, I need to see the critical facilities in those counties."
"I need to see the critical facilities in harm's way."
"Display the structures in the counties in danger in southern Florida."
"It appears that the storm is going to make landfall here, how many mobile homes will be affected?"

IMPLEMENTATION:
The decision maker makes a circular gesture that indicates the three southeastern most counties in Florida, and the zoom operation changes the display window's full extent to those three indicated counties, and adds the appropriate layer.
**SCENARIO #1 CONTINUED:**

**POINT IN POLYGON**

**SPOKEN COMMAND:**
"Which shelters are within the storm surge for a category 3 hurricane?"

**IMPLEMENTATION:** Conduct an intersection between a polygon layer and a point layer and then a database return of only the points within that polygon.

**DISPLAY ATTRIBUTE INFORMATION**

**SPOKEN COMMAND:**
"What is the capacity of this shelter?"

**IMPLEMENTATION:** Highlight the individual shelter (a point) that the decision maker indicated and display attribute information about its capacity that is stored in the database (e.g. number of beds, resources, who is in charge of re-supply).

Figure 7.3: Scenario #1 Developed for DAVE_G prototyping

The scenario above was not used directly by the design team because it was judged to be too limited in the variety and kind of user actions. The technical team needed more variety in the spoken language commands to build a natural language grammar file. They also required more sample statements so that individual nouns could be replaced with deictic referents (this, those, that, here, there, etc). To meet this request, I compiled a list of spoken commands and statements that the emergency managers use to request maps from the transcripts collected during the CTA. Those statements appear in the following text box.
7.3.2 DAVE_G Scenario #1 Addendum: Additional Command Prompts

**COMMAND PROMPTS:**

What are the critical facilities in this county?
Display the *critical facilities inside the impacted region.

*“critical facilities” is a generic term, the system should support display of all terms in the critical facilities dataset (see figure 6.X)

Are there any roads that typically would flood with a high tide and a CAT 1 storm?
This bridge is washed out; what is an alternative evacuation route?
This road is marked “closed”, but is it passable by emergency vehicles?
Which roads would be washed out by a CAT 1** storm?
**(substitute CAT 1-5)

Show me the low lying areas that typically flood.
Show me all of the mobile homes within the potential flood zone***.
*** surge zone, wind swath, region, county, projected impact region, plume model, etc
How many mobile homes are in this area?
What’s the evacuation clearance time for this county?
Where are our logistical staging areas (LSAs) located?
Show the LSAs in the impacted region.
Where are our resource distribution centers? Where are the mobilization sites?
Where is the forecasted damage swath located?
Where is the eye of the storm expected to track?
How many people live in the floodplain in this county?
Of the hospitals and adult living facilities that have to relocate, which ones are in the low lying areas of the storm surge?
We need to see our main area of operations.
The commands included above are examples of what the emergency managers described as the way they request information during planning meetings and from their GIS staff. While pointing to maps, the experts indicated they would say “I need to see all of the X in Y.” The GIS analyst would then create the maps at the scale requested. Participants indicated that there was very little negotiation between the emergency manager and GIS analyst (a noted exception is when too many symbols were displayed on a single map and the GIS analyst prompted them to select fewer layers). For the DAVE_G development team, many of these commands were found to be too complex for implementation. Thus, a second, simplified scenario was requested.

7.3.3 DAVE_G SCENARIO #2: Supporting Diverse GIS Functions

As the DAVE_G project progressed, the development team requested more scenarios of emergency response. Scenario #2 was developed and appears below, starting with a narrative to set the stage. This time, hurricane specific information was left out, so that the commands and interactions among emergency managers were more general. The scenario was developed to describe activities within three stages of emergency management: planning, response and recovery.
Flooding scenario for Lake Okeechobee

A tropical storm that began in the Gulf of Mexico is slowly moving in a north easterly direction and expected to track across the center of the Florida Peninsula. This scenario includes examples of subtasks for the planning, response, and recovery stages for the flooding impacts associated with this Tropical Storm. The flooding potential for this storm is extremely high, and could produce levels similar to a 100 year flood.

The Lake Okeechobee region has a historical precedent for flooding. In much of the state, sheet flooding occurs, meaning that a whole body of water will move across the land due to a lack of riverine features and hydrological drainage.

PHASE 1: Planning (hazard vulnerability assessment)

MANAGER:
“Show me the potential inundation area for a flood in this region.”

DAVE_G:
“I have flooding data for 50, 100, and 500 year floods, which would you like to see?”

MANAGER:
“Show me the 100 year flood dataset.”

MANAGER:
“I want to know the population that’s going to be impacted by this flood”

DAVE_G:
“I have the following population datasets: population by block, block group, and census tract, which would you like to see?”

MANAGER:
I’m really only interested in the elderly population. [system ignores first statement]
Are there any adult or assisted living facilities within the inundation zone along here? [makes a linear gesture along the river flowing north out of Lake Okeechobee].

MANAGER:
We need to evacuate the elderly in these nursing homes; will any of the evacuation routes be affected by this flood?

DAVE_G:
“These areas will be impassible.”
[displays all roads intersecting the flood layer in bright red]

MANAGER:
We need to keep this portion of the evacuation route open [gestures along the road feature that parallels the river].
Is there a dike located nearby so that can begin sand bag operations and mitigative strategies?

DAVE_G:
[displays dikes near the identified vulnerable roadways]
PHASE 2: Response (mapping flooded regions)

The storm was stronger than predicted, and the river is flooding beyond the managers’ expected levels. The task now is to increase the buffer zone around the flooded areas, and identify the regions along X river where hazardous storages sites (HAZMAT facilities) are located.

MANAGER:
Dave, the flood was 5 feet higher than we thought it would be. Can you increase the inundation area for the entire flooded region by 5 vertical feet?

SYSTEM: Dave would have to recomputed the inundated area by adding 5 feet to an originally requested flooding level potential. This is a hard problem, and DAVE_G does not have sufficient elevation information to compute this task.

DAVE_G:
“That operation cannot be performed due to insufficient data.”

MANAGER:
Alright, that’s fine. On average, the flood extended 100 feet beyond the inundation areas that we planned for, put a 100 foot buffer around the initial inundation area.

DAVE_G:
“Would you like 25 or 50 foot buffer divisions?”

MANAGER:
“25 feet”

“Show me all of the HAZMAT facilities within the new region.”

PHASE 3: Recovery (soil and water sampling)

DAVE_G enabled the emergency manager to identify the location of a 5,000 gallon diesel fuel tank with a high probability of spilling its contents into the river as a result of the increased flood levels. Ideally, the emergency managers would want to know how far down the creek the fuel had been carried given the current forward speed of the flood waters and an estimated time since the tank failed. This is a goal that seems out of reach under the current system, but DAVE_G would be helpful in identifying the locations of intakes for water treatment facilities downstream of the ruptured tank.

MANAGER:
“The fuel leak stretches from here to here [gestures along a river].”

“Show me all of the water treatment facilities within this area.”

DAVE_G:
“There was an error in identifying the river. Please gesture again.”

MANAGER:
“From here to there.”

SYSTEM: DAVE_G displays all of the intakes within the region.

MANAGER:
“We have to conduct soil sampling exercise within that area. Please place 5, 10, and 20 mile buffers around each of those intake valves for sampling activities. Thank you.”
DAVE_G Scenario #1 was developed in mid June, 2002. After receiving Scenario #1, the design team requested more realistic statements, and were provided with the additional command prompts. While many of the command prompts were too complex to instantiate, the team asked for even more complex scenarios, particularly in relation to a larger number of example statements of commands and information requests and indications of spatial referencing. DAVE_G Scenario #2 was developed the first week of September 2002. Once implementation began, some aspects of that scenario proved to be much more difficult to support than others – so the design team requested refinements (removing some of the complexity added in the list of command prompts and in Scenario #2). After reviewing Scenario #2, design goals and technological constraints of the DAVE_G project required the scenario to be refined and simplified. The scenarios were rewritten, and the language was simplified, with some nouns and pronouns replaced with deictic gesture commands. The emergency manager’s statements and commands were simplified as well; instances where the user would ask DAVE_G a question were replaced by commands (i.e. the phrase, ‘show me.’) Pieces from the two scenarios above were merged into the following scenario, implemented within the DAVE_G prototype system.
DAVE_G INSTANTIATED SCENARIO: Storm Surge Flooding I

A tropical storm that began in the Gulf of Mexico is slowly moving in a north easterly direction and expected to track across the center of the Florida Peninsula. Storm surge from both rainfall and high seas causes much of the coastal region to flood.

[DAVE’S DEFAULT MAP VISUAL DISPLAY CONTAINS A MAP OF THE CONTINENTAL UNITED STATES WITH STATE BOUNDARIES DISPLAYED]

MANAGER:
Dave, there is a tropical storm.
[Dave, loads the data for tropical storms] (This initial statement could be used in other contexts to load data for wildfires, earthquakes, radiological release, etc)
Dave, show me the southeastern United States.
[Dave zooms to the southeast US]

Dave, show me this area.
[User indicates the central region of Florida, Dave shows the following – layers displayed include counties, hydrology, and interstates for reference].
Historically, the Cape Coral and Fort Meyers area floods badly.

**Dave, show me the areas that will flood.**

**DAVE_G:**
“I have flooding data for Tropical Storm and Category 1 through 5 Hurricanes, which would you like to see?”

**MANAGER:**
“Dave, show me the storm surge flood zone for a Category 3 hurricane.”

**MANAGER:**
“I want to know the population that’s going to be impacted by this flood”

**MANAGER:**
“Dave, show me the population within the flooding area.”

**DAVE_G:**
“I have the following population datasets: population by block level and population by county, which would you like to see?”

**MANAGER:**
**Dave, show me the population by block level.**
We have a lot of people here, but I’m really only interested in the elderly population.

**Dave, show me the assisted living facilities.**

**Dave, show me only the assisted living facilities within the flooded region.**
We need to be prepared for a larger flood.

**Dave, create a 100 foot buffer around the current surge zone layer.**

---

### 7.3.5 Summary of DAVE_G Scenario Development

One goal of the KE activities was to develop realistic scenarios to guide design efforts for the DAVE_G prototype gesture speech interface to a GIS. In achieving this goal, the project was
attempting to effectively replace the GIS analyst with an “intelligent” system that could respond to a crisis manager’s requests directly without the manager needing to learn specific GIS commands. I had a secondary goal to develop scenarios of work in context that were as realistic as possible (and thus, not yet altered by external technological or project constraints) and general enough to be used for other applications (e.g., training crisis managers, design of GIS, etc.). However, in all of the scenarios above, realism was abstracted into simplified versions of what the emergency managers might say during an event. Yet by keeping the initial versions (Scenario #1 and #2) as realistic as possible, they serve as the long term vision for technologic support, and the subsequent instantiated versions can always be replaced with the initial examples. The process of creating and refining the scenarios helped the team refine and identify the specific technological and project goals for the prototype development. The scenarios served as a concrete envisioned design that allowed sub teams to focus on constructing the elements required to instantiate the design.

In the next section, I present specific, recommended methods for representing scenarios that evolved from the lessons learned during the development of the scenarios designed for DAVE_G. These scenarios were also developed from the elicited knowledge, but the focus of this final section is on a more formalized means of presenting scenarios.

7.4 Recommended Methods for Presenting Scenarios

As mentioned earlier, scenarios come in a wide array of formats. For example, in the section above, several scenarios were presented, with text and visual images used to describe the situations. In the remaining portion of this chapter, I highlight a more formalized mechanism to represent scenarios. The scenarios that follow were developed from data collected during the onsite KE sessions. The first section presents a high level summary scenario of hurricane planning and response. The next section presents two script scenarios, more detailed accounts of specific emergency situations. These categorizations have similarities to Rossen and Carroll’s (2002) problem scenarios (descriptions of current work practice) and activity design scenarios (descriptions that transform current activities into new design ideas). A noted difference is that these representations are intended to help summarize elicited knowledge and structure it in a way that leads to the creation of visually enhanced scripts of work activities, and not only text descriptions of work.

The summary scenario is a mechanism for creating a high level outline of the events and actions over an extended period of time. Within this outline, the situation, actors, actions, and information requirements are listed. The summary scenario represents the raw material from which to build more detailed script scenarios. A single ‘scene’ in a summary scenario can be the basis for a complete script scenario. The more elaborate script scenarios include visual storyboards and an accompanying script. These script scenarios are called storyboard script scenarios that are essentially
variations of storyboarding and script writing. This type of scenario combines two elements common in the movie making industry. It contains the script itself, (fashioned after a dramatic play or a movie screenplay) and the storyboard (generally pencil sketches created to dictate what the camera should depict during filming and here represented as mock ups of screen shots illustrating actions). Elements such as plot discussion, characters and actors involved, and the motions and directive elements can be added to augment the content. As in plays, where the actions of individual actors are presented, these scripts can present both actors’ actions and system based events such as “a text box appears highlighting information.” The storyboard script scenario is characterized by a dual column presentation format with text and system information on the left and visual images on the right that illustrate what the actors in the scenario would see on their computer display. Similar verbal/visual scripts are often used in advertising, corporate videos, documentaries and in movie production. As mentioned, Rossen and Carroll (2002) present a similar conceptualization of scenarios (problem scenarios and envisionment scenarios), and in geography specifically, Monmonier (1992) use of graphic scripts to design interactive maps represents an early, and related example of these types of representations.

7.4.1 Summary Scenarios: Hurricane Wilma

Writing scenarios is a process of informed creativity. In an effort to help systematize the scenario creation, I have stratified the knowledge elicited during the CTA into some of the core components (actors, actions, information requirements, etc) required for designing a detailed script. This summary scenario is based on information elicited during onsite visits, with a majority of the information identified during procedural concept mapping about the activities and actions of decision makers prior to landfall of the hypothetical storm, Hurricane Wilma.

The summary scenario below models the high-level activities and actions during hurricane response. A high level structured summary scenario such as this represents a template from which to extract specific scenes of interaction that can be elaborated into more detailed script based scenarios (similar to those generated for the DAVE_G project). The summary scenario can help prioritize the focus of development. If a design team’s goal is to support collaborative planning sessions, then the information highlighted in the opening scene (63 hours out) of the summary scenario would be used to write a detailed script of a sub-scene that contained explicit discussions of individual actions and interactions with other collaborators and computer displays. Another sub-scene could discuss only issues related to evacuation decision-making and the presentation and discussion of hypothetical situations given a backend modeling system that could estimate traffic densities, and unforeseen or unpredictable circumstances such as changes in the storm strength or path. A third sub-scene could be created from the individual elements related to logistics and operations. In this scene, the focus
might be only on the specific activities for ordering, distributing, and tracking relief resources. This sub-scene could explore resource allocation tasks with several map based technologies designed to display the locations, size, and availability of resources for response efforts. A single summary scenario can yield a number of sub-scenes that can help describe activities and human interaction with advanced technologies. The key issue is to set a clear project goal, and then identify the sub-scene that is most appropriate for meeting that design goal.

The following summary scenario is an account of the activities, actors and maps and sample dialogue requests identified by emergency managers that would be used during the Hurricane Wilma mission scenario in Florida. This summary represents a structure of key elements of a scenario, essentially the raw materials that can be molded into a script. Note, that the emergency managers use scenario planning during their own meetings. The structure of the plot is based on the Hurricane Wilma Mission Scenario discussed in Chapter 5.

<table>
<thead>
<tr>
<th><strong>Summary of Actions, Decisions, Events, and Information Needs</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>before Landfall of Hurricane Wilma</strong></td>
<td></td>
</tr>
</tbody>
</table>

The hurricane program manager and information and planning chief have been monitoring a tropical storm identified by the National Hurricane Center. They meet in the Information and Planning director’s office to discuss the current NHC advisory. It indicates the storm has reached Hurricane status of Category 0. It’s Sunday evening, and the storm is over 72 hours from landfall. The two planners notify the EOC director of the storm’s status, and a collaborative planning meeting is scheduled as the first item of business on Monday morning.

### 63 Hours Before Arrival of Gale Force Winds
Planning Room, off EOC  6 am Monday Morning

A meeting is convened among several decision makers to discuss the protective action recommendations for Hurricane Wilma. The storm is now 62 hours away, and still a weak storm at Category 0. The participants involved in the planning meeting are the EOC Director, Operations Chief, Hurricane Program Manager, Information and Planning Director, and the GIS Manager.

**COLLABORATIVE ACTIONS & INFORMATION REQUIREMENTS:**

The directors develop plans and identify protective actions by discussing hypothetical scenarios about where the storm will make landfall given historical knowledge of hurricane behavior. During this phase, the directors request a variety of maps specific to their individual responsibilities for the vulnerable locale. Among the requests are items stored in the database labeled as critical facilities. Priority is placed on those regions that require evacuation, with specific attention paid to the special needs populations (assisted living facilities, shelters, nursing homes) in the Florida Keys.

The GIS team verifies data readiness (database updates from road construction, traffic accidents, etc) for the southern portion of Florida. The EOC Director raises the EOC activation level from III to II. During the meeting, the decision makers discuss the timing of the decision to evacuate.
the Florida Keys. They discuss how to handle congestion areas (choke points) on the bridges, the need for traffic or lane reversals along evacuation routes, and historic evacuation situations. The decision makers make requests for the following: current satellite information, HURREVAC outputs, track probabilities, and evacuation clearance times.

INDIVIDUAL ACTORS & ACTIONS:

**EOC Director:**
- “Show me the projected winds and show me the projected storm’s cone of impact.”
- “Show me the potential LSA sites.”

**Hurricane Program Manager:**
- “Display the evacuation zone maps”
- “Display the evacuation routes.”
- “Show the vulnerable population totals by county.”
- “Show the vulnerable critical facilities.”
- “Show the evacuation clearance times (minimum amount of lead time prior to the arrival of tropical storm force winds required in order to clear all of the vehicles that leave those evacuation zones and get past certain strategic regional or county bottlenecks)”

**Info and Planning director:**
- Project the number of mobile homes and single family homes in low lying areas (flood plains, surge zones, low lying areas, etc).
- Determine the total population within those regions.

**Operations Director:**
- Identify any localized situations that would cause an increase over normal population (events, holidays, tourist profiles, etc.)

**ACTIONS:**
- Recommend voluntary evacuation of Florida Keys and activate traffic counters.

**60 Hours Before Arrival of Gale Force Winds**

**ACTORS:** same as before

**ACTIONS:**
- Determine the likelihood of extreme conditions (e.g. storm increase to Cat 4 or 5) and adjust planning recommendations accordingly.
- Begin preparing LSA package orders.
- During planning meetings, vulnerable counties are patched in via conference calls to identify their protective action recommendations.

**48 Hours Before Arrival of Gale Force Winds**

**EVENT - STORM PASSES CUBA, ENTERS FLORIDA STRAITS**

Whereas before, smaller groups of decision makers needed specific information for small group meetings, now, the SERT team is collaboratively weighing issues, making decisions, and taking actions. Briefings are conducted twice a day in the EOC with reports from organizational elements (e.g. director, meteorologists, information and planning, operations, etc). ESFs meet to develop plans for response activities and report in briefings.

**ACTORS:** Governor, EOC Director, Operations Chief, Hurricane Program Manager, Information and Planning Director, GIS Manager, Logistics Chief, liaisons from Florida Highway Patrol, Department of Transportation Officials, County Officials from each vulnerable county, and ESF personnel.
COLLABORATIVE ACTIONS:
• Elevate EOC to Level I – full activation
• Recommend staged evacuation for Florida Keys
• Begin evacuation monitoring
• Conduct conference calls with vulnerable counties
• Reposition resources that are in the storm’s current projected path
• Determine alternative Logistical Staging Areas in the event they are flooded or inaccessible
• Deploy Forward Damage Assessment Teams
• Request maps of the at-risk populations (assisted living facilities, shelters, nursing homes, etc)
• Establish Area of Operations
• Investigate special situations that would cause an increase in the local population

INFORMATION REQUIREMENTS:
• Resource type, locations, numbers, and reserves
• Asset relocation zones
• Critical facilities (all are requested, depending on specific location and storm type)
• At-risk populations (population in impact zone, population in low lying flood prone regions, mobile home parks, barrier islands, adult assisted living facilities, flood prone regions in Lake Okeechobee)
  • Planning maps depicting area of operations
• Information and Planning deploys personnel to Hurricane Liaison Team in the NHC
• Deploys Advance Emergency Response Team with a Logistics Trailer for Mobile Command

33 Hours Before Arrival of Gale Force Winds
EVENT - NHC issues Hurricane Watch

ACTORS: All listed above with additional personnel depending upon location specific needs

COLLABORATIVE ACTIONS:
• Recommend voluntary evacuation for all special needs populations
• Recommend evacuation of hospitals, marinas, Naval and Air Force assets
• Recommend mandatory evacuation of RV parks and tourists in the keys
• Consider issuing voluntary evacuation for South Florida
• Monitor Evacuation Process
• Monitor Deployed Resources
• Monitor Shelter Status

INFORMATION REQUIREMENTS:
• Evacuation population, traffic counter data, traffic volume, closed roads, etc
• Open shelters
• Determine and monitor shelter status (group in charge, location, capacity, status)
• Locations of Logistical Staging Areas, mobilization sites, and all deployed resources
• Stream river gauge data

21 HOURS OUT –
EVENT - NHC Issues Hurricane Warning

ACTORS: All listed above

COLLABORATIVE ACTIONS:
• Warning prompts mandatory evacuation order for south Florida counties in path
• Reposition damage assessment teams
• Split the area of operations into AO1 - northern watch zone and AO2 - southern warning zone
• Coordinates with Logistics
• Finalize LSA orders
• Finalize relief aid orders
• Deploy resource delivery teams
• Deploy law enforcement to control looting

INFORMATION REQUIREMENTS:
• Evacuation patterns
• Traffic counter data
• Current hazard information
• Estimated Damage in dollars based on storm size / history from TAOS
• Maps of AO1 and AO2

12 HOURS OUT
ACTORS: All listed above
ACTIONS:
• GIS team ensures all datasets are updated
• Reposition resources as needed
• Consider opening shelters of last resort
• Ensure completion of the evacuation
• Finalize locations of LSA and all resources
* Confounding variable: Increase in strength, sudden change in track might force more evacuations

The above account of collaborative decision making activities before a hurricane makes landfall represents a high-level view of the emergency management process. It presents examples of specific decisions that are made at specific points in time before a hurricane arrives. It also provides details of the information requirements needed in support of those decisions. Designers of emergency management decision support technologies for hurricane management should develop technologies that consider and support the actors, the decisions, the activities and the information needs outlined in this summary scenario. Summary scenarios are a mechanism for representing such information. Specific elements in the summary scenario above used in the DAVE_G scenarios include: identification of special needs populations in the flooding region, identification of mobile homes, determination of vulnerable critical facilities, protection of evacuation routes, etc.

The Hurricane Wilma summary scenario provides a template for outlining high level activities that occur over a temporal period of several days before hurricane landfall. Obviously, few disasters have such long lead times prior to the event. During the onsite visits several past events were discussed that were unrelated to hurricanes. The list of topics discussed during onsite sessions appears below. Not all of the situations below were discussed in detail, and I do not report on them specifically in this dissertation. I present them here to show that, while my research was focused on
### Train wreck
- Freight / HAZMAT (situational assessment, evacuation)
- Passenger (situational assessment, public notification, field office mgmt)

### Nuclear Power Plant
- Particulate release (release of radioactive particles over a populated region)
- Full containment breach (plume modeling, in place sheltering, provision of aid)
- Evacuation (in place sheltering)
- Mapping Emergency Planning Zones (EPZ)

### Hoof and Mouth Disease Outbreaks
- Containment through traffic control points, team deployment
- Carcass disposal site selection and deployment

### Flooding
- Prioritization and reconstruction of washed out bridges
- Road closure mapping
- Protection of sewage lift stations (map potential flooded areas, identify sewer lift stations in those regions, preventative sandbagging)
- Flooding in cemeteries (obtain dates of cemetery internments, identify new internments, model water pressure over the area)
- Process for evacuation of special needs populations in floods (cardiac and oxygen patients)

### Tornado
- Mobile GPS tornado swath mapping for damage assessment

### Fire
- HAZMAT fire support (plume modeling)

### Wildfire
- Mobile real-time mapping

### Drought

### Special Events
- Large concerts, biker rallies, etc.

### Chemical Spill
- Chemical release in a waterway

### Terrorist
- Release of cesium in stadium (plume modeling)
- Weapon of Mass Destruction (WMD) event (dirty bomb)

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Hurricanes, during knowledge elicitation sessions, emergency managers discussed several other emergency situations in relation to collaborative decision making and the use of geospatial information technologies. By returning to my original transcripts, I can extract individual mission scenarios for each of these types of emergencies. Moreover, for those involved in understanding other types of emergencies or developing technologies to support crisis management, this list represents a sampling of the types of situations that emergency managers must plan for and train to support.

#### 7.4.2 Script Scenarios

The summary scenarios present the high level information that can be transformed into more detailed script scenarios. As described earlier, script scenarios focus on the details. Specifically,
they elaborate on the scene, the situation, the collaboration among actors, their activities and their
individual and joint interactions with technology. Two variations of script scenarios are presented
in the following subsections. The first is intended to communicate an envisioned idea for a wide
audience (and thus, not just as a mechanism for assisting with designing technology). The second
scenario also communicates an envisioned idea for systems design, however is developed in the dual
column format, with more detailed representations of the work activities, system activities, and visual
images to demonstrate specific visual representations for onscreen display. This version is intended
to provide a detailed account of the activities and actions to help improve technology design for an
interdisciplinary team.

7.4.2.1 Script Scenario 1: Nuclear Particulate Release

I developed a script scenario based on discussions (prompted by critical incident probes) of
the release of nuclear particulates from the Crystal River nuclear power plant. This scenario is
depicted below. The format for presenting this scenario is compressed into a multi column display,
as it is intended more for communicating a conceptual design for a general audience and not for a
design team. It was developed to illustrate interaction between multiple field based teams and a
centralized gesture speech controlled GIS deployed in the EOC that would support envisioned
distributed, multimodal decision making GIS for the GeoCollaborative Crisis Management (GCCM)
project (http://www.geovista.psu.edu/grants/GCCM/). The scripts are a mechanism for
communicating an envisioned idea for a new technology in the context of real world situations.
7.4.2.2 Script Scenario II: HAZMAT release in an urban region

A second script-based scenario exemplifies the dual column display of a storyboard script scenario. The following scenario was developed to communicate the desired system functionalities to the design team, is based on a potential HAZMAT or chemical release in a highly populated region. While the action takes place in the New York / New Jersey area, the activities of the scenario are concerned with one of the primary activities in emergency management – rapid response and recovery. These activities were discussed during the hurricane Wilma concept mapping sessions.

With immediate impact events such as hazmat releases and train wrecks, or during the period right after the hurricane has made landfall, overcoming the ‘fog of emergency management’ is the number one priority. One participant stated that with quickly unfolding events, “the main thing is setting up a staging area, setting up a command post or [determining] where the command post will be set up and then getting satellite imagery over that.” With slower developing events, they often have a bit more time to preposition resources, but the goals immediately after impact remain the same.

This scenario illustrates the process of overcoming the ‘fog of emergency management.’ As one participant pointed out, situational awareness is achieved by first mapping the hazard boundaries, often with real time imagery. If the hazard threatens a population, evacuations follow. The
participant indicated that with rapid onset disasters and slower developing disasters, emergency management could be broken down at its simplest level into 1) evacuation decision making 2) damage assessment, and 3) resource deployment. The following scenario was built to illustrate the decision makers’ goal to overcome the immediate uncertainty during a disaster, and highlights the process of focusing in on the type and location of the hazard. A team member, Sanshar Kettebekov, developed the initial conceptual idea for this scenario during an internship with the Port Authority, and I built the detailed version from information collected during the knowledge elicitation sessions.

Scene 1: NY-NJ Chemical Incident Identification and Display

INT. EOC COMMAND CENTER

There are two large screen displays. The LEFT display contains the mapped images and GIS layers; the RIGHT side consists of power point slides. On the left screen, a satellite image of the PA-NY-NJ district is displayed. An explosion not far I-78 has dispersed an unknown material. Multiple, incoming 911 reports indicate fire, smoke and strong odor of rotten eggs and a large cloud rising from somewhere near the I-78. Each report is displayed in text form on the RIGHT screen:
- 9:21 White smoke reported from exit I-78 58b
- 9:23 Fire reported visible from exit 56 on I-78
- 9:24 Smell of rotten eggs reported from McCarter highway near railway crossing

The EOC MANAGER approaches the screen, and begins his task of identifying the attributes and spatial location of the hazard.

MANAGER
There are multiple conflicting reports coming in of an accident on I-78, display the interstates.

Interstate (major road) layer is added to the display, and appear as solid blue lines.

MANAGER
Place an incident marker at exit 58b on Interstate I-78.

A red dot appears on the display at that location.
MANAGER
Zoom to this area.

Gestures to an area surrounding the new incident report indicated by the white box at right. Display changes to a new image of the zoomed in region.

MANAGER
Place another incident mark at exit 56.

Another red dot appears at the given intersection.

MANAGER
Mark this report as smoke, potentially a fire.

Symbology of mark at exit 58b changes to a white cloud.

MANAGER
Mark this incident as fire.

Symbology of mark at exit 56 changes to a flame symbol.

MANAGER
We need to pinpoint the locations of the reported chemical release. Zoom to this region and display the roads.

Gestures the white box to indicate new extent.

(Optional) SYSTEM
There are data for both major roads and local roads, which would you like to see.

MANAGER
Display the major roads.

MANAGER
Highlight MacCarter Road.

MacCarter road is displayed in light blue.
<table>
<thead>
<tr>
<th>MANAGER</th>
<th>Overlay the railroads that intersect with MacCarter Road.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The railroads intersecting with MacCarter road are displayed in green.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MANAGER</th>
<th>Mark this incident as a potential chemical release.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gesture indicates the intersection between MacCarter and the railroad line. A new incident mark is made, displaying the chemical release icon.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MANAGER</th>
<th>Show the HAZMAT facilities in this area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The computer returns no hazmat facilities for that region.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(OPTIONAL)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The manager makes a broader gesture for a larger region and again requests the HAZMAT facilities. The system locates a couple facilities outside of the area of operations, and the manager, having identified no potential threat, returns to his duties.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MANAGER</th>
<th>We need visual verification of the location of the potential chemical release so that we can deploy a chemical damage control team.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display all known live video sources in the region.</td>
<td></td>
</tr>
<tr>
<td>The system loads a layer that</td>
<td></td>
</tr>
</tbody>
</table>
indicates three live video feeds in the area.

MANAGER
Access this one.

Indicates desired video feed. The video stream is displayed on the other screen.

Subsequently, a new text message appears: “RAIL AUTHORITY REPORTS AN ACCIDENT ON FREIGHT LINE 1.”

MANAGER
It looks like the source is west of the RR and freeway intersection. Mark this location as a HAZMAT incident.

The system changes the symbology to mark a HAZMAT incident at the newly indicated location.

MANAGER
What railroad line is this?

Gestures along the green Railroad line – and a database query returns information box on the linear feature displayed in a text box. “FR1 – operated by the Norfolk Southern RR, carrier of HAZMAT.”

MANAGER
Assign priority as level 1 and broadcast the incident.

A text display on the right displays the list of designees.

SYSTEM
Select the designees for the broadcast.

MANAGER
Send it to these agencies...

CLOSE
7.5 Summary

This chapter has presented the evolution of scenario writing for the design of advanced
geospatial information technologies. Specifically, the role of elicited knowledge for informing
scenario writing and lessons learned from scenario use on the DAVE_G project were highlighted.
The chapter concluded with three examples of formalized scenario representations for technology
design. The summary scenarios were found to be a useful tool for presenting all of the information
available to designers. The summary scenarios can be used to create more detailed, storyboard script
scenarios for designing envisioned technologies.

When combining elicited knowledge into emergency management scenarios (especially
mission scenarios to support knowledge elicitation) the script writer must merge several pieces of
information. In authoring the scripts, I relied on four heuristic guidelines to assist with the creation of
the scenarios. Each of these guidelines is discussed in the following paragraphs.

First, the scene and timing should be explicitly defined (e.g. Monday, 8 am) because in all
emergency and crisis situations, the time of day, time of year, and day of the week all influence the
decision making activities. The scenarios I used did not specify the date, and thus, the emergency
managers noted that the time of year, and thus, the date was incredibly important element in decision
making, and had a significant influence on their actions and decisions. Both South Carolina and
Florida have seasonal population spikes, requiring them to determine the number of tourists and
visitors during emergency management activities.

Second, the locations of the action (emergency event) and the actors (responders, decision
makers, and vulnerable populations) should be identified. For hurricanes specifically, small
variations in the storm track can significantly alter the affect of a storm surge, or the impact of winds
depending on the structure type in the line of the storm. While decision makers try to plan for all of
these possible variations, scenario writers should focus on a specific area to learn about the decisions
important for that region.

Third, the actions and decisions of the actors for a specific event should be structured over the
course of the script. As demonstrated in the decision making diagram in Chapter 6 (Figure 6.28)
emergency management activities is an iterative, self building process. Decision makers weigh
information and initiate an action. That action changes the nature of the next decision, and the
process continues iteratively throughout the event. The structure can be developed and extracted
from mission scenarios and procedural concept maps.

Fourth, it is important to have a list of critical incidents and descriptions of past events to
provide 1) a foundation for identifying new mission scenarios both related to the specific incident and
for other situations such as nuclear events, floods, and other emergences and 2) detailed information necessary for filling in the script and placing it in a given context.

In this research, the elements of the CTA each provided unique pieces of information that have been molded and interwoven into specific scenarios of emergency and crisis response. I believe that the foundation of scenarios should be based on the actual work practices as observed or elicited from experts in field work. The procedural concept maps and stories discussed during critical incident probes provided necessary background to create a foundation for scenario creation. The abstraction hierarchies can also assist in building an understanding of the primary goals of the work that a scenario describes and help couple those goals with the specific physical units on the ground that assist in emergency management. Decision making diagrams and decision ladders can also help the researcher explore and represent the structure of typical decision making activities within a specific scene. Recall the decision ladders in Chapter 6. Each decision ladder is anchored at a specific point in time (for example 33 hours before landfall). The decision ladder can be compared with the summary scenario presented in this chapter, to provide detailed structure for the development of scenario scripts.

Based on this field experience, aspiring scenario writers can flexibly adapt the elicited information of work into envisioned designs of technologies to propose future situation in an envisioned world. This chapter has discussed the nature of scenarios, provided examples of their use in developing technology, and described the relationship between knowledge elicitation and scenario writing. The methods employed in this CTA provided a foundation and primary elements required for writing realistic scenarios.
Chapter VIII:
Conclusions & Future Research

“so with a hundred ‘modern improvements;’ there is an illusion about them; there is not always a positive advance...Our inventions are wont to be pretty toys, which distract our attention from serious things. They are but improved means to an unimproved end, an end which it was already but too easy to arrive at...”

-- Henry David Thoreau --

“A man is rich in proportion to the number of things he can afford to let alone.”

-- Henry David Thoreau --
8.1 Summary

Geographic research is often characterized by the researcher’s ability to synthesize information gathered at multiple scales of analysis into a holistic understanding of a problem. This research has sought to develop a ‘deep’ understanding of the use of geospatial information during emergency management response to hurricanes. Similar to studies of the global human-environment system, a comprehensive understanding of work can be obtained through an emergent and comprehensive examination of the complete system and the specific components within it. So, for emergency management, studying the high level goals as well as specific individual agencies and workers who achieve these goals was approached from a holistic viewpoint.

This research implemented a CSE approach to eliciting expertise and modeling the explicit, tacit and inferential knowledge to improve understanding of work and to guide the development of new technologies for emergency management with specific application to the development of DAVE_G prototypes. Specifically, the field work helped determine the common uses of geospatial information in emergency planning and decision-making and incorporated that information into realistic scenarios of work.

Knowledge elicitation activities were conducted in three stages, offsite data collection, onsite visits and post-visit verification and design (via e-mail, phone, and post). The results from the entire process were used to create formalized concept maps, abstraction hierarchies, decision making diagrams and decision ladders and requirements listings of hurricane response activities. The information, taken collectively, was used to create summary and script scenarios of envisioned designs that are supporting design of advanced mapping systems for use in hurricane response. The remainder of this section summarizes the research and provides insight into how it has helped to improve our understanding of work with geospatial information in emergency and crisis management.

In chapter two, a review of literature in the field of Cognitive Systems Engineering suggested that a CSE approach to understanding, modeling, and designing technologies for work has the potential to improve the design and development of geospatial information technologies. One goal of this study, complementary to the goal of understanding work with geospatial information technologies, has been to demonstrate the value of this approach through a detailed application to the context of geospatial information technology use in hazards and emergencies. In relation to hazards and emergencies, I build on a framework proposed by Tobin and Montz, but argue that that an additional dimension needed to be added to Tobin and Montz’s framework for studying disasters: the technology dimension.

In chapter three, I presented a three stage CSE approach for studying work in the tradition of the Living Lab. The approach combined multiple converging techniques into three stages of offsite,
onsite, and design work for understanding work with geospatial information in emergency management facilities.

Chapter four presented the offsite work, which focused on an initial task identification of the use of GIS in emergencies. The results from this stage of the research indicated that most of the tasks carried out by the ESFs in emergency response (after the event) required geospatial information at one level or another. Specifically, most of the tasks required GIS technology to create simple, geospatial reference maps for decision makers, while the more complex analytical functionality of GIS were not used. The more complex analysis was often accomplished with other programs that supported spatial display of information (HURREVAC, TAOS, HAZUS, etc). GIS was used primarily to support the display and overlay of information layers. Buffers were commonly used to highlight areas of concern on generated maps. GIS was also important for creating specific products like route maps for resource deployment and search and rescue strip maps. Another critical issue was ensuring that the maps were continually updated and displayed recently acquired time critical information during emergencies. The participants indicated that important uses of GIS included real-time data updates of damaged facilities, resource locations, and power outages and information queries of those areas to develop statistical tables. A questionnaire used to elicit this information also informed the development of data requirement tables needed to support emergency management activities.

As part of the off-site preparation, I took an online emergency management course. This course emphasized the importance of understanding the physical and social impacts of a hurricane hazard. Specifically, the course introduced software mapping tools (HURREVAC) used in hurricane emergency decision making. The course also covered issues of hurricane hazard uncertainty that influence decisions, the development of emergency operations plans and a general introduction to the process and timing of decisions and response activities during hurricane emergencies.

In chapter 5, I detailed the onsite work with professional emergency management personnel. The experts participated in knowledge elicitation exercises aimed at uncovering the use of geospatial information during the four stages of emergency response. The participants indicated that the core function of GIS in emergency response was spatial referencing support, or showing one element such as a HAZMAT storage facility relative to the hazard. The creation of maps that support spatial referencing required simple GIS operations such as show and display layers, alter the extent/scale of the map, buffer affected regions, and identify attribute information about the facility or layer in question. Some of the most common emergency tasks for which these operations were used include evacuation support, relief supply positioning, search and rescue, environmental and animal protection, and resource supply tracking. This research has found that the use of GIS (and not necessarily
geospatial information) at least in terms of the pre-impact stage of hurricanes, remains limited but is expanding significantly. The utility of geospatial information to responders and emergency managers during the pre-impact stage is being increased by the movement towards field based, mobile geospatial technologies that relay information from the field to a command center location.

The onsite work contributed significantly to the development of a deep understanding of work in emergency management centers. Each state and the agencies within them have unique social and organizational decision making structures. In studies of emergency management, it is critical to understand the structure and identify who is in charge as that structure significantly changes the decision making activities. One important element affecting the activities and decisions is the interaction across scales from the federal to local level. FEMA provides the support to the state agencies that in turn coordinate and provide support for the counties. The counties manage the responders (from ESFs and associated organizations). The responders carry out the necessary work activities to secure life and property during emergencies. This support network has flexibility in that state organizations can take over for counties that become unable to coordinate and respond to the disaster. In order to promote collaboration and coordination, the divisions hold multiple conference calls, produce detailed information reports and situational updates, and conduct EOC briefings to disseminate information and update all parties about the protective actions being taken. Liaisons are established within EOCs to ensure that the information is communicated to the organizations and first responders in the field.

Related to the role of maps and geospatial information, emergency managers use a large number of decision support technologies, and do not rely on any single output or display more than others. They collaboratively discuss and weigh the map based information from weather reports, GIS, and other decision support tools and make recommendations and decisions based on their assessments of those materials. Maps and geospatial information are already used in support of nearly every task required in emergency management; however, the amount of information becoming available and the role of geospatial information to assist decision making was rapidly expanding due to the technological advances of GIS and GPS technology. This continued development and expansion of mapping technologies was a common theme discussed at all sites. Each participating division, in various stages of GIS development, suggested that GIS had not yet achieved its potential to improve emergency management decision making, and ongoing efforts would likely continue to improve decision making activities through the provision of geospatial information support. The divisions were using large screen displays to show maps in both conference rooms and in the EOCs. They were also focusing on using new GPS based field mapping technologies, both in hand held devices, laptops, and computer mapping workstations deployed via trailers at disaster field offices.
Standards for mapping activities across states and divisions were not in place and, thus, sharing of data across counties and states represents an ongoing area requiring improvement.

The formalized results of the information collected during the onsite work presented in chapter 6 provided further insights into the nature of work with geospatial information. The Abstraction Hierarchies were useful for identifying the goals of emergency responders, and in examining the overall structure of the social organization of distributed emergency management. The concept maps represent models of the process of emergency response held constant across specific teams with a temporal dimension. The information collected and represented on the maps helped identify information about specific individual’s work during emergencies, and when taken collectively, identify the nature of collaborative group decision making during hurricane response. They helped identify the specific timing of decision making and mapping activities as a hurricane approaches. They uncovered key themes and the specific response activities within each theme (themes were planning and preparation, evacuation, sheltering, provision of relief supplies, damage assessment, and information management). They also uncovered information about the uncertainties in the hazard, in the evacuation, in sheltering, and in the immediate damage as the storm comes ashore that affect emergency decision making. The concept maps provided representations of the large number of emergency responders who must coordinate their efforts in response from the federal to the local level. They also contained detailed information about the information requirements needed for developing a database to support emergency decision making. Decision making models were produced to distinguish between the process in South Carolina and the process in Florida. Decision ladders helped examine the degree to which heuristics, past experience, and gut instincts compress deliberations of potential decisions into action as the impending threat nears.

All of the information collected during the CTA was combined into scenarios of emergency management activities in Chapter 7. The process of transforming elicited knowledge into scenarios of envisioned designs was described. Specifically, the relationship between knowledge elicitation techniques, representations of the knowledge, and the role of that knowledge in writing scenarios was discussed. Finally, three strategies for the presentation of that information as summary scenarios and script scenarios were discussed.

8.2 Discussion of the Approach

This dissertation has applied a Cognitive Systems Engineering approach to understanding work with geospatial information in emergency management. Specifically, a three stage Cognitive Task Analysis was conducted. No single approach to CTA dominates, and often, despite the increase in CTA research, best practice for conducting a CTA remains a ‘dark art’ and represents a significant challenge for researchers embarking on a CTA. Part of this barrier exists because Cognitive Systems
Engineers have often conducted CTAs on business sensitive information and classified military work; thus the specific details of the methods remain hidden. The barrier also exists because CTAs often focus on only the results of the analysis and not the details of the methods. I have attempted to document the specifics of the field work carried out for a CTA in emergency management to help future researchers develop strategies for applying these methods to individual research projects.

A Cognitive Task Analysis is often an evolving, iterative process. A long noted difficulty in applying a CTA is the bottleneck that exists between the expert and the knowledge engineer or elicitor. Another bottleneck, however, can at times prove even more problematic. Once the data are collected, how can the information be presented to design teams (such as that for DAVE_G) and other interested parties quickly and efficiently? Both of these bottlenecks represent significant challenges for novices and experts applying techniques of CSE.

Specific to this research, efforts were made to improve the efficiency of producing results and iteratively incorporating them into the prototypes. First, offsite work yielded results that could be immediately provided to the development team so that work on the technology side could proceed. These results led to the development and support of a gesture speech GIS that supported functionalities of zoom, pan, add/remove layer. Second, onsite visits were conducted, and preliminary results were quickly converted into envisioned scenarios (see DAVE_G Scenario #1 in chapter 7, created 2 weeks after field work concluded) that would allow the development team to continue to expand the prototype system to incorporate advanced queries (intersections) and more geospatial operations (buffers). As the project leaders focused development work, new scenarios were created to meet the project’s design goals. Third, the concept maps were formalized and provided to members of the design team so that the information on the representations could be used to identify the information requirements that required database support.

Of these three, the first two were successful in communicating designs and pushing forward the development of the DAVE_G system. Concept maps are supposed to improve understanding of a domain, and to help the reader examine the information and process it quickly, without having to read pages of text. Most proponents of concept map representations cite a major advantage of them to be their self explanatory structure and the ease at which the information on them is communicated to the reader. While I was able to use the elicited information displayed on the concept maps to identify the actors, scenes and structure for scenario writing, the use of concept maps to inform the internal design of the DAVE_G prototype was less efficient. Specifically, unfamiliarity with the representation format of concept maps created difficulty in transforming the representations into a semantic basis around which to extract design features, information requirements, or to design the database engine and dialogue query manager. The difficulties in extracting useful knowledge from the concept maps
could be a deficiency in the static paper-based format I chose for their presentation or in the level of
detail of the concepts depicted versus those required for system design. Because they were not digital
and searchable, it made it difficult for individuals who had not created the concept maps to extract
knowledge from the formalized concept maps. This also suggests that the color-coding scheme
applied to the concept maps to make reading them easier and to reduce the complexity of the concept
map structure could be improved with detailed explanations to accompany the individual procedural
concept maps in order to be more useful to assist with the design goals of the DAVE_G project.

The sheer amount and diversity information presented on the concept maps can make them
initially appear overwhelming to a reader. I believe that the abstract representations require
individuals to undergo a focused period of study before they can develop an understanding of the
content and begin brainstorming about how that information can be transformed into designs. Just as a
user of a traditional geographic reference map cannot expect to immediately understand all there is to
know about a new place by a cursory examination of a USGS topographic map, equally so, one
should not expect to be able to understand a complicated, highly collaborative decision-making
process like hurricane response by a brief examination of a procedural concept map. Two ways I
simplified the concept maps were by constructing them with consistent events along the timeline
(achieved through mission scenario prompts) and also by adding color to the representation in order
to focus attention on desired information. Nevertheless, despite these changes, I believe that there
remains significant room for improvement communicating the information contained on abstract
concept map representations and making that knowledge more useful to readers and designers.
Mechanisms to make concept maps more useful as a design media could include focused
‘bootstrapping sessions,’ where all design team members independently and collectively study the
information on the maps in an effort to develop a basic understanding of the representation format
and the information they communicate. The ‘bootstrapping sessions’ could be prefaced with
individual summary descriptions (as in Chapter 6) of the concept maps content to help develop a
preliminary understanding of the representation itself as well as the content each map represents.

To illustrate the use of concept maps as a brainstorming tool, I draw on experience from a
workshop with software developers who were creating command and control systems for the military.
At this workshop, the concept maps from Florida were used as a prompt for developing ideas for an
EOC based ‘system of systems’ to support emergency management decision making. Teams of 5-8
software developers with experience in developing next generation command and control interfaces
for the military viewed the concept maps, and were asked to develop ideas and diagrams of the
features needed for a command and control emergency management support system. After studying
the concept maps, the teams brainstormed and presented ideas about what an emergency management
command and control system would need to support. Most groups focused on a need to differentiate between event-based decision making and time-based decision making activities. They suggested that the system should be stratified into operational modes based on the current operational conditions (normal, hurricane watch, and hurricane warning, response, recovery, etc). A key issue the groups identified was the development of technologies that supported the integration and display of real-time, dynamic data (for example, shelter status, evacuation status, time to impact, etc). One group suggested stratifying the system into a data management system (for all emergencies), and an asset management system (displaying all available resources for that event) and an event management system (stratifying information according to different disasters). To support collaborative decision making, the integration of enabling technologies such as videoconferencing, collaborative drawing tools (on map based displays) and simulation models that provided information on appropriate placement and relocation of resources were suggested as important features. Another group suggested that each decision maker should have a prioritized inbox based on the decisions and the amount of time the decision maker had to act. The degree to which events triggered actions of individual personnel was also identified as an important design consideration, with actions determined by matching events to decision makers based on their occurrence on the timeline. This experience with the software developers (who had no prior experience with concept map representations based on work in practice) suggests that concept map representations are an effective means for brainstorming ideas for new technologies and interfaces, providing encouragement that concept maps can augment the design process.

I believe that the static concept maps could still be useful for developing this emergency management ‘system of systems.’ This ‘system of systems’ would have knowledge of every individual worker within emergency management, allow unobtrusive access to information (such as natural, gesture speech interaction with a large screen display), and coordinate and control the display of information to those individual decision makers and responders. In this hypothetical system, each individual’s procedural concept map could be converted into procedural models that preserve the semantic information contained on individual nodes. This model would serve as the basis for a customized, temporally defined profile that contained information about the tasks and data requirements of individual users. Thus, for example, if the operations chief approached the DAVE_G system, a unique profile containing the order of information requests and the probable timing of information requests could be loaded. Simultaneously, a database containing the associated information layers required to support those requests would preload information for rapid access by the user. The database would be developed and refined iteratively, based upon past situations, activities, and customized additions. If the operations chief was responding to a hurricane,
information specific to that disaster would be loaded along with generalized information about the
operation chief’s information requests during other emergency situations or training exercises.

Over time, the system would begin to detect emergent relationships within the operation’s
chief’s profile, label them, and build new relationships. Individual profiles could be merged into
single, composite representations for specific organizations, tasks, and groups of decision makers.
Again, with each subsequent interaction within the system, social and collaborative emergent
relationships would be recognized and incorporated to yield more efficient predictive display of
information to collaborative teams of individuals. If an individual requested information about
Logistical Staging Areas, the system could deduce that they would also need information about
mobilization sites, RIAT and RECON teams, resource package orders, and population information
surrounding that LSA site. This information could be used to preload data and predict the types of
requests made by emergency managers. Time will tell whether such an approach to building an
‘intelligent system’ is feasible.

The products of this CTA, such as the concept maps discussed above, underwent expert
verification to ensure that the information was captured and represented correctly, and not
mischaracterized. The initial concept maps created onsite were evaluated for content onsite, during
knowledge elicitation sessions. Then, the formalized concept maps as well as the resulting scenarios
were sent to the participating emergency managers who evaluated, refined, and returned them. The
products from this research can be considered to be valid reflections of work in emergency
management. Nevertheless, the captured information begs the question of whether the representations
that depict what the emergency managers say they do during emergencies are accurate representations
of how and what they actually do. Further validation could be achieved by comparing specific job
duties and procedures outlined in hurricane plans, direct observation and post-hoc analysis of
decisions and information used during actual events. Follow up research will include direct
observation and comparison of findings from that observation to results presented here.

While the concept maps proved to be difficult for the design team as a whole to translate into
system design specifications, they were very useful as a key input to development of scenarios. These
scenarios were effective models for prototype development on the DAVE_G project. Scenarios
derived from the CTA process demonstrated what the system was supposed to do so that individuals
with expertise in dialogue management, vision tracking and natural language processing could work
together to produce prototype systems that supported the activities related in the scenarios. The
scenarios contain detailed, specific information related to system function, but at an abstract level,
demonstrate the high level needs of decision makers. Each scenario was presented and distributed to
the entire development team. These scenarios were revisited often, and revised with even more
frequency. These scenarios represent benchmarks that indicate how system development proceeded throughout the project’s lifespan.

Potter et al. (2000) suggest that CTAs should help practitioners anticipate new technologies, future research endeavors and to develop new, envisioned designs. This research was successful in helping to anticipate the need to build geospatial information support for mobile devices, an emerging technology in emergency management. It was also successful in developing new areas of research focus. The following section discusses future research challenges identified, demonstrating the predictive power of this CTA procedure.

8.3 Recommendations for Future Research

8.3.1 Overcoming the knowledge transfer bottleneck

As highlighted in the discussion above (about the difficulty of using static concept maps as design tools), future research needs to consider how we can transform elicited knowledge into more useful representations that support system design and refinement. Representations of knowledge are not enough; the information needs to be accessible and relevant. Because people learn and process information differently, the same knowledge might have to be expressed in different ways to make sense to different people. While a concept map representation might be appropriate for one person, a more structured representation might be more appropriate for another as evidenced in Zaff et al. 1993 where concept maps were useful for knowledge elicitation with pilots, IDEF-0 was useful for systems engineers and storyboards were appropriate for human factors engineers.

The ability to take represented knowledge (such as a static concept map) and transform it into a representation-independent format and then display the content in a new representation (such as a decision ladder) is an exciting challenge. Without a means for converting, transforming and representing knowledge in different forms, the elicited expertise stays locked in the format in which it is represented. Efforts towards integrating concepts, persons, tasks, and relationships into a searchable knowledge system dubbed CODEX, with support for concept mapping tools, are being developed at Penn State (Pike et al., 2003). This effort is aimed at encoding concept nodes with a deep semantic structure based on concepts and their associated properties within a given context. The thought is that researchers can search within a created concept space to uncover ontologies, social networks, and spatio-temporal structures of similarity.

There remain several challenges towards the integration of elicited expert knowledge about work with computing systems. Elicited information, like the real world work practices, is, more often than not, non-linear, ill-defined, and chaotic in structure. Research needs to focus on how to elicit and transform such heterarchical information into a format that can be represented in computing systems. Rule structures allow easy integration of hierarchical structures in computers, however,
integrating heterarchical structures remains a research challenge. This issue becomes even more significant when adding issues related to uncertainty.

Work during ill defined, time critical situations such as crisis management often contains high degrees of uncertainty. Further complicating the issue is the complexity of social organizations and collaborative decision making. Another challenge is to develop mechanisms for encoding information based on past experiences like explicit knowledge and expert based heuristics and tacit knowledge in decision making contexts. Such representations also have the potential to preserve institutional expert knowledge. Emergency management, like many domains, has a high turnover rate. By streamlining the knowledge elicitation and representation process, institutional knowledge can be more readily preserved and transferred to other individuals.

8.3.2 Appropriate Knowledge Elicitation Techniques

An underlying theme of CTA is that it is opportunistic and that the selection of techniques is left up to the researcher depending on the goals of the specific project. Researchers would benefit from guidelines that inform which specific techniques yield a particular type of result and for what types of applications a given technique is appropriate. Such guidelines would increase researcher’s accessibility to the methods and extend the utility of the techniques to practitioners in other domains. An example of matching techniques with designs would be an examination of the techniques (concept maps, critical incident probes, questionnaires, etc) that are most appropriate for collecting knowledge to write scenarios. Efforts to stratify the results of techniques and systematize and describe their role in scenario writing can help future researchers select knowledge elicitation techniques to support technological design.

Determining the degree to which two techniques complement each other when used simultaneously remains an exciting research opportunity. Critical incident probes and concept mapping were combined during this research, and the two techniques were complementary, with concept mapping providing the structure necessary to identify the procedural activities and the critical incident probes providing tacit knowledge from recollection of past events. More research on the interplay between critical incident questioning and concept mapping is an important focus of inquiry. The use of multiple techniques is of further importance to understanding teamwork.

Lessons learned in this research on the combination of procedural concept mapping anchored by mission scenarios with specific anchor points to maintain consistency for all participants suggest that the combination of those approaches is appropriate for studying teamwork. This approach was intended to improve understanding of team collaboration during emergency events. However, while the results of the concept maps were compiled into formalized concept maps, they were not searchable or linked within a computer system. Moreover, they could not be overlaid with one
another to see how the activities and jobs of two individuals interrelate. Support for overlay, similarity and difference comparisons, and the identification of areas of agreement across individual’s concept maps that are anchored by a temporal component would allow researchers to improve their understanding of teamwork.

Procedural concept mapping (achieved through the inclusion of timelines) is only one technique that could lend itself to studying team performance and collaboration. Explorations of knowledge elicitation with collaborative teams and the subsequent representation of that knowledge in decision ladders, social networks, and abstraction hierarchy representations has the potential to improve our understanding of how time affects team performance and collaboration.

8.3.3 Eliciting Spatio-Temporal information

The field work revealed that concept mapping was a useful knowledge elicitation method for understanding group work with geospatial information, but that standard concept mapping techniques need to be extended to include temporal elements. The concept mapping exercises with domain experts (emergency managers, field workers, etc.) used a linear representation of time to allow experts to visualize, explain, discuss and revise processes, concepts and interactions. This technique has helped improve understanding about the decision making process.

I believe that by exploring temporal anchors (specific events with a concrete temporal occurrence), we can improve our understanding of not only the nature of temporal events during work activities, but also its influence on human activities. In the concept maps that I produced in this research, a centerline represented the person being interviewed and their activities across time. The individual’s specific activities and actions were linked to that centerline, explicitly. I believe that the linear temporal anchor (or timeline) is probably most appropriate for tasks with short durations. For work over longer periods of time, temporal anchors based on specific events seem more appropriate. For example, the concept map could be propagated from specific events (tropical storm forms in the Caribbean, hurricane warning issued, landfall of tropical storm force winds, hospital destroyed, etc). Research on methods for eliciting temporal knowledge is an important research challenge.

Also important are techniques for eliciting spatial information. Elicitation methods to identify specific spatial locations of actual work practices have the potential to extend and improve standard concept mapping knowledge elicitation techniques. Achieving this goal would be difficult unless the work were studied in context, through observation. I believe that the concept mapping techniques can be extended to spatial representations in a couple of different ways.

In Figure 8.1, a sample representation of how procedural concept mapping conducted on a real map (instead of blank paper or a white board) might look is presented. In this example, the map would help with the elicitation and discussion of location specific information. Localized information
important to the task being discussed can be represented at its source. In this manner, the map would serve as the communication medium for knowledge transfer through which the knowledge elicitor and expert develop a shared mental model of the situation. This type of representation would help improve our understanding of things with a geographic or Euclidian structure, but would impede representation of temporal structure, social structure, scale hierarchies, etc. Research should focus on how to combine multiple concept maps with specific spatial, temporal, and social structures for building a complete understanding of the problem context.

Figure 8.1: Concept map with spatial anchors

In Figure 8.2, the locations and movements of teams are depicted directly on the base map. This example highlights how a knowledge elicitation session aimed at uncovering information about specific movements and communications between distributed teams could be conducted on base maps. Each individual would be presented with the same base information, and then relate their own knowledge about the procedures and activities of the field teams according to specific locations. This type of KE activity could help with scenario creation by providing explicit cues about the location of resources and movement of supplies for resource management. Knowledge elicitation conducted in
this way also has the potential to improve understanding of situational awareness. By tying specific teams to locations at particular times, the point at which situational awareness is improved could be identified. If extended to teams in other domains, a collective model for efficient achievement of situational awareness could be developed.

Figure 8.2: Map Based Action Map:

Team A is instructed to evaluate an LSA site, and then proceed to 1st, 2nd order activities or an alternative LSA site depending on their findings. Team B is affected by Team A’s activities, and must shift their work activities based on Team A’s findings.

8.3.4 Improving Situational Awareness

A major challenge for research in emergency response, supported by evidence discussed in chapters 4-6, is to develop better methods for understanding and tools to support situation awareness. Improving situational awareness through better visual and verbal communication is an important research area in emergency response. By applying current technology to the scenario above, all damaged areas could be managed from a centralized GIS database. The GIS could be made accessible, through multiple PDAs and laptops, in real time, to logistics and recovery teams deployed in the field. Research should focus on how real time, distributed access to critical information relayed between teams in the field and the emergency operations center affects team performance, team cognition, and team communication. With established metrics for evaluating team performance,
research could shift to developing an improved understanding of how team performance affects the decision making of emergency managers in EOCs during distributed collaborative situations.

Research should focus on how geospatial information technologies equipped with GPS have the potential to significantly improve situational awareness. Specifically, in the emergency management context, the focus of future field research should be tied more closely to specific teams (damage assessment teams, ESF workers, disaster field offices, etc) involved in planning, response, and recovery. Research should also focus on Rapid Impact Assessment Teams (RIAT) and RECON teams that provide time critical information in the first 24 hours, a time frame considered critical to restoring order after an emergency. Studies in this period can improve our understanding of team performance and the role of geospatial information technologies in time critical situations. The CTA presented in this dissertation should be viewed as a launching point for investigations of future technologies that can contribute to crisis response, and in turn, be extrapolated to other areas of use such as homeland security or public participation and planning.

### 8.3.5 Improving Geospatial Information Access

This research has demonstrated that maps and mapping technologies vary significantly from the federal to local level as well as within and among states. Standardized methods and approaches to presenting geospatial information have not been implemented across emergency management divisions. Post 9/11/01, the Federal Geographic Data Community Homeland Security Working Group led an effort to standardize map symbols. An initial symbol set has been developed, but the project is still considered an ongoing work in progress. Research that evaluates symbol effectiveness across teams and geographic regions in time critical situations is needed.

Emergency management agencies often use geospatial information in similar ways, however the specific software packages, the precision and accuracy of data, and the mechanisms for storing and distributing the information varies among county and state EOCs. While national efforts are underway to improve interoperability and standardization of information and its subsequent onscreen display, more research in this area is needed. The results of this study suggest that CSE methods have the potential to improve the understanding of the nature of work with geospatial information technologies and thus, improve and advance efforts on data interoperability and cross state and agency standardization.

Along those lines, standards for the subsequent display of that information on large screens and mobile devices for supporting individual work and team collaboration is also an important research area. Our understanding of the nature of collaborative interaction with geospatial displays (especially large screens) remains limited. Research should focus on developing theoretical foundations for interface designs that are robust enough to support real-time collaborative interaction.
with a map for multiple individuals. Research should also evaluate the influence of display technologies on individual and group work with geospatial information.

**8.3.6 Understanding Human Behavior in Emergencies**

An ongoing research challenge is to improve our understanding of how human behavior affects decision making in emergency management. One challenge is to integrate current models of human behavior during evacuations and crises and make that information available readily available to decision makers via new technologies. Another challenge is to collect more data about human behavior that emergency managers identified as contributing factors to uncertainty (e.g. the presence of boat trailers and RVs, distance traveled, shelter use, etc). Once collected, the data need to be modeled and represented in real-time geospatial information displays for emergency managers. With such models, researchers could begin to examine whether the models improve the effectiveness or timeliness of decision making, or in fact, introduce additional variables that hinder decision making.

**8.3.7 Presenting and Communicating Event Related Uncertainty**

One of the most difficult aspects emergency managers face are event related uncertainties. These uncertainties often stem from the unpredictable conditions associated with uncontrollable weather events that drive many crises. Hurricanes, for example, have a high degree of uncertainty in the impact area, storm track, storm strength, impact timing, a rapid strengthening, rain vs. wind events. Maps are one mechanism that can be used to display the uncertainty associated with hurricanes. Research needs to focus on appropriate representation and visualization strategies for communicating event related uncertainty to decision makers on geospatial information displays.

**8.3.8 Cross Hazard Comparisons**

CTA techniques have the potential to improve vulnerability and risk assessments. Vulnerability assessments as well as risk and loss estimation are important for developing community, all hazard response plans. The information collected during this research related mostly to efforts in hurricane response. However, studies of hurricane hazards are not sufficient to fully understand emergency and crisis decision making. CTAs that focus on tornadoes, nuclear events, acts of terror, earthquakes and other emergencies can help validate the findings of this research and expand our knowledge of decision making in command and control situations, more generally. Once a critical mass of information has been reached for all hazards, cross hazard comparisons can help identify the universal issues that emergency manages and first responders have to deal with, regardless of the disaster being managed.

**8.3.9 Development of Planning and Training Systems**

With the rapid advances in computing technologies, it is becoming increasingly difficult to keep up with the explosion of software and technologies. Research needs to focus on the
development of training systems and training programs to for emergency management. A gesture speech enabled platform such as DAVE_G has the potential to improve training in a range of application domains, not limited to exploration of alternative scenarios in emergency management. For example, such systems could support public planning efforts, military command and control, and geographic education.

In crisis management, each disaster provides responders with new situations and problems that they had not encountered before. These situations often highlight the need to obtain new data and information related to that specific occurrence. Several participants indicated times when data were not available to the decision makers when it was most needed. If emergency responders were provided with a training system that allowed the emergency managers to interact and respond to a variety of crises during the off-season, problematic or unanticipated situations could be identified and the data could be obtained in advance of actual emergencies. Such systems would not only help emergency managers, but the training systems would also serve as test-beds for researchers to then study collaborative interaction and use of geospatial information in real world situations.

8.3.10 Considerations of Scale

An important component of studying emergency management decision making is the examination of work at appropriate scales of analysis. Research needs to focus on developing models of geospatial information use at multiple scales (county to federal). Research can also address the role of an individual’s mental model on the perceived need for geospatial information. For example, at both the state and local levels, emergency managers build up extensive knowledge of the local area, especially those areas that are prone to disasters. This local area knowledge contributes to the individual’s mental map for a particular location. Thus, for the experienced veterans, the need for geospatial information differs significantly from recent hires in emergency management divisions. High turnover rates in emergency management divisions could create situations where new hires were ill-equipped to execute the necessary actions required for an emergency event. Thus, understanding the individual mental models and collective mental models of geospatial information use at multiple scales is important to promote the persistence of institutional memory. Such studies should focus on the collaborative sharing of geospatial information by Emergency Support Functions at the county, state and federal levels. The development of individual and organizational models of geospatial information use has the potential to improve collaboration, as well as the development of technologies to augment collaborative work activities.
8.4 Final Thoughts

The results of this multistage CTA achieved both goals outlined in chapter one. First, the information collected was processed and used to promote the development of a deep understanding of geospatial information use in emergencies. Second, the knowledge was merged into scenarios that served as a basis for iterative technological design for a prototype gesture speech interface to a GIS. The scripted scenarios are not only important for technology development as envisioned designs, but they are also important characterizations of work geospatial information during emergencies. I believe that scenarios should describe work in context, preserving the real world work practices, and then be adapted for specific technology design applications later, such as the specific scenarios developed for DAVE_G. The scenarios are representations of common goals that collaborative design teams can utilize to prioritize development and develop new ideas for technologies.

The information technology revolution has created a situation where software development has fallen behind the capabilities of the hardware. However, with the outsourcing of code writing, software design has the potential to catch up to the hardware. A fundamental shift is taking place from writing code and developing technologies in a techno-centric approach (i.e. because it can be done) to designing software and technologies to support specific work activities. Homeland security is a critical focus of research and technology development. However, as software companies compete to build the next best software application, they can potentially overlook the more important element of the equation, understanding work. This issue is particularly important for domains where life and death decisions are made. In these instances, technologies should be designed based on real world work practices in specific contexts.

Envisioned designs communicated as scenarios are crucial for fundamental advances in technologies. Rather than constraining research and development to the current world view based on existing technologies and computing capabilities, focus needs to be placed on envisioning systems that heretofore have not been built. In meeting this goal, it is imperative that experts are included as participatory designers to ensure that the technologies are appropriate for the demands of the work domain. To maximize the role of experts in designing advanced, domain specific technologies, the development strategies need to shift focus from proof of concept demos and prototypes to actual working systems so that the experts can interact with new technologies, and suggest alterations and changes to the software design teams, ultimately improving the usefulness of the technologies.

Making geospatial information technology easier to use by crisis managers and related decision makers will help to increase the efficiency of coordination and control in strategic assessment and crisis response activities by both civilian and defense authorities and personnel. To
achieve this goal, emphasis needs to be placed on how expertise and actual work practices can be communicated to software developers; scenarios represent one such method for achieving this goal.

Cognitive Task Analyses are designed to improve understanding about the work activities in a domain of practice. Woods (1987) advocates that in the end, the value of conducting CTA lies in its impact on improving understanding of the domain of practice, construction of usable designs that are also useful for the population they were designed for. The CTA reported here provided a significant amount of information to improve understanding of the individual collaborative activities in hurricane response. While insight was gained about collaboration, the individual responders, the actions, decisions, processes and structure of work, perhaps more interesting is the information that was not uncovered. For example, prior to completing the CTA, the premise was that maps and geospatial technologies were widely used in the pre-impact period before hurricanes make landfall. In fact, the findings indicate that GIS use is more concentrated in the post impact period, but that a need exists for integration of real time sharing of information among distributed teams during the pre-impact period. The research suggests that this goal will be met through investigations into distributed teams and mobile geospatial information technologies.

The information collected during the CTA was usable in that it was transformed into multiple representations of work that include formal procedures (from the bootstrapping exercises), procedural concept maps (from the combination of mission scenarios and concept maps) and diagrams of the decision making process and the structure of work in emergency management. These elements were used to create scenarios of use that were based on real world activities as related by emergency managers. These scenarios served as the basis for development of prototype gesture speech systems. Because the technologies are based on actual work, the technologies have taken the first step in being usable for the domain of practice. Future refinement to the technologies developed for the DAVE_G project require further testing, both in laboratory settings and in real world settings as advocated by the Living Lab. Finally, the results of the CTA were useful in that they uncovered intricacies in the domain that were previously not considered (such as the importance of teams and mobile technologies). This information helped inform the focus for a subsequent interdisciplinary research project, GeoCollaborative Crisis Management currently underway at Penn State (http://www.geovista.psu.edu/grants/GCCM/).

This holistic study indicates that future investigations in the use of geospatial information in the context of emergency management should be focused spatially and temporally. The spatial narrowing should seek to expand our knowledge about the decisions and activities during immediate response and recovery activities at municipal and county scales of analysis. Specifically, for rapid response, communications between multiple teams of distributed field responders and a local county
level EOC are important. For recovery operations, the focus on technologies that allow for monitoring resource deployments and sampling reports of air quality, water quality, and localized situational occurrences were most important.

The temporal focus of future research should be stratified to develop a deeper understanding of each individual stage of emergency management (such as response and recovery). This research found that specific, detailed information such as the exact time of the day, the day of the week and the month of emergency significantly influences the maps and activities of emergency managers and responders, both in the field, in incident command posts and in EOCs.

This research has demonstrated that the methods of CSE have the potential to improve our understanding of work with geospatial information technologies. As researchers design new mapping and information technologies to support work in hazards research, spatial and environmental decision making, human environment interaction, vulnerability analysis, and resource management and city planning, it is imperative that researchers develop a deep understanding of real world work practices, to ensure that the maps and technology developed is not only usable, but is useful for the workers for whom it is intended. Without a focus on improving our understanding of the use of geospatial information, we could contribute to the proliferation of diverse technologies that are unable to meet the challenges of work in the coming century.
REFERENCES


FEMA Training course Hurricane Course: http://meted.ucar.edu/hurricane/chp/hp.htm


Appendix: Preliminary Questionnaire

I. Identifying the typical tasks in hazard management

First, please read through the following list of 17 Emergency Support Functions and their associated response tasks. Select the four most common to hazard response requiring the use of GIS. While this research is most concerned with the tasks that require GIS use, further interest lies in identifying the most common types of activities performed in emergency situations, therefore, if a task is extremely important, but does not require GIS, then indicate the task (and note that GIS is not required). Next, select four tasks that are also important and require GIS operations. If the list is incomplete, then please add the missing task to the list in the space provided. If you are able to prioritize the four activities, rank order the tasks from 1 to 4 with 1 being most important.

- **TRANSPORTATION** - provide transportation support
- **COMMUNICATIONS** - provide telecommunications, radio and satellite support
- **PUBLIC WORKS AND ENGINEERING** - provide support in restoration of critical public services, roads and utilities
- **FIRE FIGHTING** - support detection and suppression of wild land, rural and urban fires
- **INFORMATION AND PLANNING** - collect, analyze and disseminate critical disaster information to state emergency response team members
- **MASS CARE** - manage temporary sheltering, mass feeding and distribution of essential supplies for disaster victims
- **RESOURCE SUPPORT** - provide logistical and resource support to other organizations through purchasing, contracting, renting and leasing equipment and supplies.
- **HEALTH AND MEDICAL SERVICES** - provide health, medical care and social service needs.
- **SEARCH AND RESCUE** - locate lost persons and victims trapped in collapsed structures and provide immediate medical care.
- **ENVIRONMENTAL PROTECTION** - respond to actual or potential hazardous materials discharges and other situations threatening the environment.
- **FOOD AND WATER** - secure bulk food, water and ice to support mass care needs.
- **ENERGY** - support response and recovery from shortages and disruptions in supply and delivery of energy resources.
- **MILITARY SUPPORT** - provide military resources to support logistical, medical, transportation, and security services.
- **PUBLIC INFORMATION** - disseminate disaster related information to the public.
- **VOLUNTEERS AND DONATIONS** - coordinate utilization and distribution of donated goods and services.
- **LAW ENFORCEMENT AND SECURITY** - coordinate the mobilization of law enforcement and security resources.
- **ANIMAL PROTECTION** - provide rescue, protective care, feeding and identification of animals separated from their owners.
- **OTHER – TYPE IN YOUR ANSWER HERE:**
II. Task Description

From the four tasks identified above, please indicate the specific procedures that require GIS use within the emergency management situations. In either sentence form, or a bulleted list, describe the typical, step-by-step procedures for accomplishing the selected task (see the example below for details). Next, if the task selected above was ANIMAL PROTECTION, list GIS commands (e.g. buffer operations, data queries, etc) to ensure the protection and rescue of the animals from the disaster event. Also list the essential datasets, with a focus on datasets that are unique to hazard situations. These lists do not need to be comprehensive, but should include the essential and unique data and operations to the identified task.

EXAMPLE
Task 1: ANIMAL PROTECTION

Procedure:
- Identify large farms
- Obtain the proximity to relief assistance etc.

Data Required:
- county or state level x roads etc.

GIS Operations Performed
- Overlay of x and y
- Buffer of x

Task 1:

Procedure:

Data Required:

GIS Operations Performed:

Task 2:

Procedure:

Data Required:

GIS Operations Performed:
Task 3:

Procedure:

Data Required:

GIS Operations Performed:

Task 4:

Procedure:

Data Required:

GIS Operations Performed:

ADDITIONAL COMMENTS:
Curriculum Vitae

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