A functional goal decomposition of urban firefighting

Lisa Fern
Cognitive Systems Engineering Lab
The Ohio State University
fern.5@osu.edu

Stoney Trent
Department of Behavioral Sciences and Leadership
United States Military Academy
stoney.trent@us.army.mil

Martin Voshell
Cognitive Systems Engineering Lab
The Ohio State University
voshell.2@osu.edu

ABSTRACT

In this paper we describe a functional goal decomposition of urban firefighting as part of a larger cognitive task analysis. Previous research indicates that firefighter decision strategies employ a pattern-matching technique that allows them to choose the first workable option based on similar previous experiences. This study builds upon this research by employing multiple cognitive task analysis methods to further examine firefighter decisions through a functional goal decomposition. The functional goal decomposition outlines the functions, decisions and information requirements of firefighting in terms of two overarching goals – save lives and protect property. Information requirements provide useful insight into the difficulties of firefighter decision-making. Though still in the preliminary stages, this project has generated a number of design recommendations to support urban firefighting. Future analyses are also discussed.

Keywords

cognitive task analysis, firefighting, functional goal decomposition, emergency response, decision making

INTRODUCTION

In recent years, the environment within which urban firefighters and other first responders operate has changed dramatically. In particular, recent natural disasters, terrorist threats and large fire incidents have created new demands and challenges for firefighters. On May 13, 2000, 20 people were killed and 300 injured when a fireworks warehouse located in a residential neighborhood in Enschede, Netherlands exploded (BBC, 2000). Ironically, eight months earlier, a similar fireworks explosion had killed 50 and injured 300 in Celeya, Mexico (BBC, 1999). On 17 July 2007, at least 50 rescue vehicles responded after a TAM Airlines Airbus 320 skidded into a building in the heart of Sao Paulo, Brazil, killing at least 200 (CNN.com, 2007). On September 11, 2001, over 10000 rescue personnel responded to the attacks on the World Trade Center (CNN.com, 2001).

Extraordinary events such as these have created a need to better understand and support the challenges of urban firefighting to minimize negative impact on practitioners and the larger organizational structure. The purpose of this paper is to present methods and findings of a cognitive task analysis of urban firefighting and illustrate how this research is supporting the development of design requirements to improve incident management and decision making, as well as aid in skill acquisition. This paper builds upon previous firefighting research, and will therefore begin by highlighting some of these contributions.

In the face of these recent changes to emergency response operations, the current project provides an opportunity to support coordination and synchronization activities through technology design. The introduction of new technology invariably changes the physical work of front line responders, as well as their cognitive and coordination demands (Woods and Hollnagel, 2006). Clumsy technology tends to hide or miss data at critical periods, hindering responders and key decision makers in the process. For example, McKinsey & Company (2002) reported that unreliable radio communications severely limited the amount of operations information available to chief officers in the lobby of the World Trade Center towers. However, technology is not inherently bad. Good designs can lessen the cognitive demands of practitioners, provide and guide attention to relevant information, and improve performance (Woods & Roesler, 2007). Overall, they provide increasing opportunity for practitioners to express their expertise. For first responders this can mean increased life-saving capabilities, response effectiveness and safety.

Cognitive Systems Engineering (CSE) is concerned with supporting natural human performance capabilities through design (Woods & Roesler, 2007). CSE recommendations for improvements in technology, organization, education and process are aimed at supporting dynamic decision-making within the context of complex, high-risk domains. Firefighting and other emergency response operations provide a rich environment for understanding cognitive and collaborative processes. For the past 20 years, researchers in CSE as well as many other fields have conducted research in urban and wildland firefighting in order to understand high-level cognitive processes where practitioners must make critical decisions. Such decision makers operate under high time pressure and in uncertain environments that have the potential to change rapidly and create huge costs to life and property. Emergency response operations typically exhibit characteristics of dynamic decision tasks: operations require a series of decisions, the decisions are not independent, the state of the task changes both autonomously and as a consequence of the decision maker's actions, and decisions must be made in real time (cf. Brehmer & Allard, 1991). A corpus of firefighting research has shed light on the decision-making processes of practitioners in domains characterized by such environments.

One of the greatest contributions to understanding decision making in time pressured environments comes from an examination of the decision strategies of urban fireground commanders (Klein, Calderwood, & Clinton-Cirocco, 1986). Based on analyses of retrospective accounts, these researchers found that instead of utilizing traditional strategies of decision-making (i.e. deliberate comparison of two or more options in order to come up with the optimal solution), fireground commanders relied on their experience base in order to generate an initial reasonable option. Employing a strategy that emphasized a quick, workable solution as opposed to an optimal solution allowed practitioners to quickly make a decision under extreme time pressure where generation and contemplation of alternatives was too time consuming. An alternative course of action was generally not considered unless there was evidence that their chosen course of action would not work. Often, decisions were judged through detailed mental simulation of how the plan of action would be carried out, rather than through formal analysis and comparison. This type of decision-making, where individuals assess the current situation, match it to a familiar prototype, and choose the first workable option is called Recognition-Primed Decisions (RPD).

The RPD model rose out of an effort to overcome the limitations of research paradigms derived from highly structured laboratory tasks with little relevance to operational domains like firefighting (Klein & Calderwood, 1991). According to this model, the quality of fireground commanders' decisions is based largely on their ability to recognize a situation as typical. Leveraging their experiences in similar instances, they are able to generate general prototypes that include causal dynamics, possible courses of action and expectations. When one of these prototypes fits their current situation they are able to make decisions quickly and effectively. When experiences are inadequate, the decision maker is unable to match a novel situation to a familiar prototype, and is forced to revert to logical thinking and deliberation of possible alternatives. Thus, practitioner experience has a large influence on one's ability to make good, quick decisions. The recognition of a situation as prototypical or novel depends primarily on the practitioner's ability to make a correct assessment of the situation as well as predict future states, given the current context. This assessment is a product of the perceptual and cognitive abilities of the practitioner, often developed through training and experience. Thus situation awareness is largely dependent on the experience of the practitioner.

While RPD provides a satisfactory description of how firefighters make decisions, as empirical generalizations it does not describe the specific cognitive work and decision requirements in the domain that can help to inform the design of systems to improve performance. Supporting decision-making is not as simple as supporting the general situation assessment skills of practitioners. It requires understanding the specific cognitive demands inherent in the domain. For example, firefighters face such cognitive reconceptualization issues as: when to make their assessments, how to react to changes in the conditions and context within which they work, what information they use, where critical information comes from and how to prioritize their goals. These, and others, have the power to influence and affect decision making and mental simulation processes regardless of which strategies are being used.

Further, this model assumes a command structure of decision making whereby one commander, or single responsible decision maker, is responsible for all necessary actions. Although in theory the command and control structure of firefighting supports the idea of a single commander responsible for critical decisions, in practice, this command structure is oversimplified as individuals in distributed teams are likely to be faced with decisions for action that can affect the entire team. The "individual decision maker" does not capture decision making in teams where decisions are distributed across interdependent groups and individuals, each with different roles, goals, and responsibilities. Therefore it is imperative that examinations of decision-making in emergency response operations take into account the role of team dynamics. Contributing to a larger cognitive task analysis, this study focuses on functional goal decomposition to uncover the information requirements that support the decisions critical in carrying out the major functions of urban firefighting.

Cognitive Task Analysis (CTA)

Uncovering cognitive activities that are required for successful task performance requires developing a meaningful understanding of the domain at hand. This is the goal of a cognitive task analysis (CTA). Cognitive task analysis does not describe a single, coherent methodology, instead it encompasses a group of methods and techniques for eliciting practitioner knowledge, capturing procedures and strategies, identifying cognitive skills, and uncovering domain demands.

Roth and Mumaw (1995) identify three basic classes of CTA techniques based on the overall goal of the analysts: formal analysis to uncover the range and complexity of tasks inherent in the domain, empirical techniques in a natural or simulated environment to assess the knowledge and strategies required in order for practitioners to complete their tasks, and computer models that simulate the cognitive activities that are required for task performance. The differences among these classes are in both the process of discovery as well as the kind of information elicited. However, these three classes should not be confused as strict distinctions, only a general categorization for referring to the variety of methods in practice. While computer models and simulations are valuable, particularly when comparing alternative system designs, a discussion of them is outside of the scope of the current study.

Potter, Roth, Woods and Elm (2000) emphasize that a comprehensive understanding of a field of practice cannot be attained through one CTA technique, particularly in complex domains where constraints limit access to the field and practitioners; "unexpected complexities and surprises are more likely uncovered when multiple techniques are employed than when the focus is on only one technique". Instead, they have presented a framework for how a variety of CTA techniques can provide design relevant results through an iterative process of understanding both the field of practice and the practitioners within. The former requires focusing on the fundamental characteristics of the field that shape performance and the latter on how practitioners respond to the inherent demands and challenges built into the domain. Thus a CTA integrates the perspectives of both the domain and the practitioners.

The differentiation between these two points of access - the domain and the practitioner, can be understood in terms of the analytic and empirical classes of approaches. Formal analytic techniques help to uncover the fundamental characteristics of the domain and the cognitive demands they impose on practitioners. Thus, analytic methods provide a framework for understanding practitioner performance and are typically conducted prior to more empirical approaches. Constraints on access to both the domain and practitioners make it critical for researchers to become familiar with the essential processes, terminology and principles of the domain in order to build rapport with domain practitioners, maximize time with subjects and make sense of the date collected (Zachary, Ryder, & Hicinbothom, 2000). This can be addressed through preliminary domain analysis. Analytic methods also provide input into the type of support that may prove useful in dealing with the complexities of the domain. These methods typically entail at least some review of existing documents that identify well-established constraints in the domain, such as training manuals, operations or procedure manuals, domain/trade publications, and system drawings (Flach, 2000). These materials may prove to have limitations however, as one discovers that actual work experiences and practices do not match entirely to those identified in the literature (Hutchins, 1995).

Other analytic approaches utilize a functional analysis. An example of a functional analysis is provided by the goal-means decomposition utilized by Roth and Mumaw (1995) to design system interfaces for a first-of-a-kind advanced control plant. The function-based CTA started with a functional goal-means deconstruction of system processes by decomposing high-level goals into low-level sub-goals and by mapping the physical means available for achieving those goals. This produced a goal-means representation of the system with specifications of the system goals, the relationships between goals, and the means for goal achievement. The goal-means decomposition provides the framework for determining the information requirements for practitioners to monitor and control system processes by mapping practitioner knowledge and decision requirements onto each of the nodes of the goal-means structure. Regardless of the method used, an analysis of the domain should provide, at a minimum, an understanding of the factors that make performance challenging, a framework for interpreting performance, and requirements for effective support (Potter, et al., 2000).

Empirical techniques provide the second perspective of a CTA: understanding the knowledge and strategies the practitioners have developed in response to the demands of the domain (Potter, et al., 2000). These methods typically focus on some version of elicitation from practitioners about the knowledge and strategies they bring to bear, and decisions they face in order for successful task performance. Knowledge elicitation typically involves some form of interview or verbal protocol while practitioners perform a task. Empirical methods may also involve some form of observation of natural or simulated environments to overcome limitations with practitioner recall and to understand the context within which tasks are performed (Flach, 2000). There are certain aspects of actual work conditions that cannot be fully appreciated until they are observed in context such as the effects of time pressure, environmental conditions, team interactions, and limitations of technology. However, Flach (2002) argues that modeling cognitive strategies solely on observations may unknowingly capture the "cognitive strategies that have evolved to compensate for impoverished person-machine interfaces". Many CTA methods employ a combination of knowledge elicitation and observation strategies.

In summary, there is not "one best" approach for a CTA. The techniques chosen for any CTA are a balance between the time and effort available, the goal of the researchers, and the knowledge required to fulfill that goal. A reasonable check for any CTA method is whether it has generated sufficient understanding and knowledge about the domain in question in order to improve individual and/or team performance given the overall constraints and goals of the system.

METHOD

As with any CTA, ours is also tailored to the characteristics of the domain, as well as our access to it, which is limited to one major metropolitan fire department. The major pragmatic constraints to the domain of urban firefighting in general include a relatively low frequency of incidents, the difficulty of observing interior fire operations, the difficulty in observing geographically distributed teams, and the safety of the researchers. Despite these, we were given a surprising level of access to practitioners and doctrinal publications that allowed us to apply both analytic and empirical approaches to our CTA.

Domain Orientation

To begin with, our research team reviewed doctrinal publications and departmental circulations such as annual operations evaluations, training curriculum and critical incident reports. Hutchins (1995) has noted that written procedures are not used by practitioners as structuring resources and they are not reflective of tasks that are performed. While doctrine, written operating procedures, and historical accounts are not truly indicative of the real work performed, they are a valuable starting point for further discovery. They serve as a basis for orienting and educating new practitioners in the domain, can reflect what is viewed as best practice, and provide an invaluable introduction to domain language and expectations for the researcher.

Building on these activities, unstructured interviews were conducted with firefighters, company officers and chiefs of varying experience and responsibilities. Firefighters are responsible for individual duties such as operating fire apparatus, ventilating fire buildings, conducting searches, and rescuing occupants with experience ranging from six months to 10 years. Company officers are responsible for supervising four or five other fighters and have five to 15 years of experience. Chiefs have the most experience (10 to 25 years) and are responsible for supervising two or more fire companies. Chiefs also have experience serving as incident commanders. Interviews during the preliminary stage of our research were typically informal and conducted during the course of their normal duties. During these interviews we asked each practitioner to describe their duties and responsibilities and asked them to describe work situations in which they were surprised or forced to adapt from their normal operating procedures. Due to the limitations of self-report data (Stone, et al., 2000; Howard, 1994), our team also observed daily operations and training exercises.

Our team of six researchers observed daily operations, incident responses and training exercises over the course of eight days. While shadowing fire chiefs in four different firehouses, our team observed a fire safety inspection, four fire emergencies, a steam pipe leak, a hazardous material release and multiple false alarms. Additionally, we observed a variety of training exercises. Two full-scale exercises, one at a high-rise commercial building and one at a shopping mall, included multiple fire battalions responding to large-scale, simulated crises. Two tabletop exercises were venues for interagency planning and coordination. As well, two company-level training exercises focused on individual firefighter and small team actions at an emergency. Table 1 summarizes all incident observations and interviews that were conducted.

Observations	Unstructured Interviews	Guided Interviews
4 Urban Firehouses (8 days w/ 6 observers)	7 x Fire Chiefs	1 x Fire Chief
<u>Exercises</u>	3 x Company officers	1 x Company Officer
2 x Full-scale exercises (High Rise & Shopping Mall)	4 x Firefighters	1 x Firefighter
2 x Table-top exercises (Shopping Mall & Government agency coordination meeting)		
2 x Company training exercises (rope training, hose training)		
<u>Emergency Responses</u>		
2 x Apartment fires		
Trash fire		
Residential basement fire		
Steam Pipe leak		
4 x False alarms		

Table 1. Observations and Interviews

Functional Goal Decomposition

Based on the domain orientation findings, we developed a functional goal decomposition (FGD) in an attempt to map the decisions and information requirements that support the critical functions of firefighting. The FGD was accomplished by first determining the major functional requirements of the fire department. Then, decisions required by each function were proposed along with the necessary information requirements. After an initial FGD was outlined from the domain orientation activities, the analysis was verified by three practitioners – a fire chief, company officer and. In a guided, group interview, these practitioners were presented with our analysis and were asked to relate personal experiences that illustrated each of the functions.

FINDINGS

Firefighting has two goals – save lives and protect property. In the pursuit of these goals, fire departments must perform five functions – manage routes, manage resources, reduce threats, situation assessment, and extract occupants and firefighters. Figure 1 provides a basic illustration of how these functions are distributed at an incident. These functions are summarized below. Table 2 outlines the decisions and information requirements that support these functions.

- *Manage Routes:* Planning and executing unit movement to and from the incident, including local paths at the incident (e.g. firefighter entrance into and exit out of the fire building).
- *Manage Resources:* Monitoring, committing, requesting and withdrawing of men, equipment and supplies at the incident.
- *Reduce Threats:* Planning, monitoring, and applying resources to the process of extinguishing, dissipating and/or containing fire, hazardous material or other environmental hazards to life and property
- *Situation Assessment:* Gathering, assessing, monitoring and analyzing current information in order to provide critical decision support at the incident. Particularly crucial is the monitoring of the progress and effectiveness of the current response strategy.

- *Extraction:* Extracting life hazards, occupants and incapacitated firefighters from the incident and saving lives.

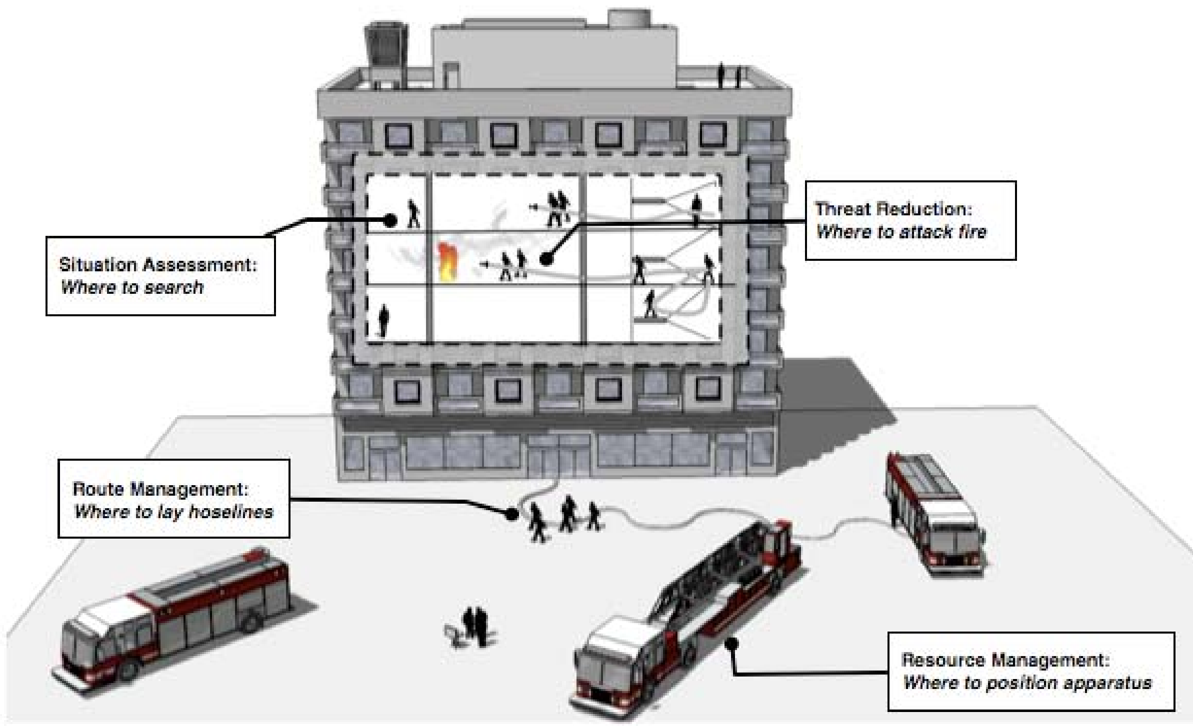

Figure 1. An Example of the Distribution of Functions and Decisions at an Incident

Figure utilizes models obtained from the Google 3D Warehouse by modelers~leus_emelem2007~, Dosy, William

Function	Decisions	Information Requirements
Manage Routes	What route to take for approaching the incident? Where to lay hose lines? What are the valid entry/exit paths? Does a path need to be created?	Infrastructure limitations Traffic patterns Routes of other responders Environmental conditions Occupancy status Confirmed life hazard Condition of roof Locations of: Incident Water sources Fire or contamination Extensions of fire or contamination Elevators, stairs, doorways, access points Obstacles for entry
Manage Resources	When and where to commit resources? When to withdraw or replace resources? When to request resources? Who to designate as a safety team? Where to establish command post and staging areas? When to request casualty coordinator? How to position ladders and pumps?	Progress of search Conditions of building Occupancy status Water supply Resource depletion Expertise/Trust in working groups Time units have been exposed Current staffing levels Unique apparatus available Status of uncommitted units Emergency responder casualties Structure type and floor plan Street conditions Locations of: Fire or contamination Extensions of fire or contamination Life hazards Resources Power lines Water sources Building entrances Other vehicles
Reduce Threat	Whether to attack or contain the fire? Reduce or contain contaminants? Need to set up/establish decontamination? Whether to ventilate or not? What substance(s) to use on contaminants or fire? Where to attack threat?	Structure type and floor plan Conditions in building Type of contamination Surrounding population Weather effects on contaminants Locations of: Fuel sources Fire or contamination Extensions of fire or contamination Hose lines

		Scuttles and skylights
Situation Assessment	Is it a false alarm? Cease or continue search for life? Cease of continue search for fire? Where to search?	Source of alarm Reports from occupants Presence of heat or smoke Fire containment Occupancy status Progress of search Exposures Structure type and floor plan Potential for flash over/back draft Resource depletion Time of day Locations of: Fuel sources Fire or contamination Extensions of fire or contamination Hose line Scuttles and skylights Stairs Life Hazard Small rooms
Extraction	Focus on threat reduction or rescue? Where to establish a safe refuge area? What is the best method for evacuation? When to deploy a rescue team?	Presence of ladder company Water supply Conditions of building Occupancy status Location of: Fire or contaminants Extension of fire or contaminants Stairs, balconies, fire escapes, elevators, exits Rescue teams Incapacitated or lost emergency responder

Table 2. Functional Goal Decomposition for Urban Firefighting

SUMMARY AND DISCUSSION

This paper has summarized the progress of an extended project to understand and design for command and control in complex environments. What is highlighted in particular, is a methodology that utilized a functional analysis to identify the functions, decisions and information requirements that should be addressed in the design of technology to support urban fire fighting operations. A functional analysis is not simply a laundry list of activities; functions capture how domain structures are adapted to purposes. The goal of any functional analysis is to capture domain structure in terms of: the goals to be accomplished, the relationships between goals and the means to meet these goals. The current methodology has proven useful for identifying how information is utilized by urban fire departments to meet their goals. Identification of information requirements indicates opportunities to support firefighting decision-making. Since the availability and nature of information changes across an incident response, one of the greatest domain challenges is updating, maintaining and disseminating relevant information. This challenge highlights the need for technology to achieve effective and efficient communications, provide critical information about environmental conditions to firefighters and commanders, and support coordination between and across the different echelons of the fire department hierarchy.

In its current form, this FGD offers no indication of the interdependencies of these functions and decisions. It also provides no insight into dynamics of this rapidly evolving work. In order to address these issues, our team is currently analyzing case studies of critical incidents and planning staged world studies of representative scenarios. While the findings of this analysis will be reserved for future publications, interviews with practitioners suggest that the pacing of decisions often leads to workload bottlenecks - too much work to do in the time available. A typical solution for workload bottlenecks is to apply more resources to the problem. This often transfers the bottleneck as coordination costs increase with the number of agents involved. Exacerbating this problem is the fact that firefighting requires simultaneous decisions to be made in multiple locations. Consequently, firefighters tend to be vulnerable to coordination breakdowns.

To address this vulnerability, this research project has generated several representation design requirements (Trent, Voshell, Fern and Stephens, 2007):

- Communications architectures should support command team interaction across multiple echelons
- Personal alerting devices should provide situational alerts (i.e. heat, smoke, injured or lost firefighters) as well as communication with their units and commanders
- Distributed decision making requires critical information (i.e. location of fire, building construction, location of water sources, downwind hazard areas, disposition of resources, etc.) to be disseminated across multiple echelons before, during and after incidents.

These design recommendations stem from the large body of theoretical and applied investigation laid out in this current work utilizing CSE techniques to gain insight of firefighting as a joint cognitive system. The insight gained from evaluating critical information requirements necessary for the cognitive work and decision making in the domain, enables the identification of leverage points from which to introduce design seeds and new design recommendations.

Because all of our data has been collected within one major metropolitan fire department, these findings must be verified elsewhere to ensure sufficient external validity. The use of critical incident analysis will help to overcome this limitation. Critical incident reports collected from fire investigations in other cities will be used as scenarios for improving our model of dynamic interdependent decision making in fire fighting. Critical incident methods take advantage of the presumption that non-routine events elicit expertise from practitioners and are appropriate when the domain places constraints on real-time data gathering. Since critical incidents from many urban and metropolitan fire departments are made publicly available by the National Institute for Occupational Safety and Health (NIOSH), they present an opportunity to incorporate important functions and decisions that were missed in the current FGD. This analysis will also provide a check to the generalizeability of our findings to other fire departments.

This project provides the basis for development of support tools for incident management and training to support current and emerging threats. The use of multiple CTA techniques was critical in overcoming restrictions to domain access. In particular, the FGD was tailored to capture the demands of urban firefighting. Further analyses have the potential give insight into the temporal aspect of the domain as well as illustrate the interdependencies of firefighter functions and decisions. They are also required to capture the functions and decisions of multiple urban fire departments. Though initial design recommendations have been generated, they serve as hypotheses about effective decision support that can lead to further understanding developed through these analyses.

ACKNOWLEDGMENTS

This paper was prepared through collaborative participation in the Advanced Decision Architectures Consortium sponsored by the U. S. Army Research Laboratory under the Collaborative Technology Alliance Program, Cooperative Agreement DAAD19-01-2-0009. We would like to thank the members of the research team that helped with data collection: Shilo Anders, Matthieu Branlat, Alex Morison, Brian Prue, David Richards, and Robert Stephens.

REFERENCES

1. BBC News. Dutch fireworks disaster. 14 May 2000. http://news.bbc.co.uk/2/hi/europe/747566.stm Accessed on 26 December 2007.

2. BBC News. Mexico explosions kill dozens. 27 September 1999. http://news.bbc.co.uk/2/hi/americas/458438.stm Accessed on 26 December 2007.
3. Brehmer, B. & Allard, R. (1991). Dynamic decision making: The effects of complexity and feedback delays. In J. Rasmussen, B. Brehmar & J. Leplat (Eds.), Distributed decision making: Cognitive models of cooperative work, (pp. 319-334). Chichester: Wiley.
4. CNN.com. Fiery plane crash at Sao Paulo airport kills at least 200. 18 July 2007. http://www.cnn.com/2007/WORLD/americas/07/17/brazil.plane.crash/index.html Accessed on 26 December 2007.
5. CNN.com. Terror attacks hit U.S. 11 September 2001. http://archives.cnn.com/2001/US/09/11/worldtrade.crash/index.html Accessed on 26 December 2007.
6. Flach, J. M. (2000). Discovering Situated Meaning: An Ecological Approach to Task Analysis. In Schraagen, J.M.C., Chipman, S.F., & Shalin, V. L. (Eds.) Cognitive Task Analysis. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.,87-100.
7. Howard, G.S. (1994). Why do people say nasty things about self-reports? Journal of Organizational Behavior, 15, 339- 404.
8. Hutchins, E. (1995). Cognition in the wild. Cambridge, MA: MIT Press
9. Klein, G. A. and Calderwood, R. (1991). Decision Models: Some Lessons From the Field. IEEE Transactions on Systems, Man, and Cybernetics, 21(5), 1018-1026.Klein, G. A., Calderwood, R., and Clinton-Cirocco, A. (1986). Rapid Decision Making on the Fire Ground. *Proceedings of the 30th Annual Human Factors Society*, 1, 576-580.
10. Post-9/11 Report of the Fire Department of New York (FDNY). McKinsey & Company, Aug 2002.
11. Potter, S. S., Roth, E. M., Woods, D. D., and Elm, W. (2000). Bootstrapping Multiple Converging Cognitive Task Analysis Techniques for System Design. In Schraagen, J.M.C., Chipman, S.F., & Shalin, V. L. (Eds.) *Cognitive Task Analysis*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 317-340.
12. Roth, E. M. & Mumaw, R. J. (1995). Using Cognitive Task Analysis to Define Human Interface Requirements for First-of-a-Kind Systems. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, San Diego, CA, Oct. 9-13, (pg. 520-524).
13. Stone, A., Turkkan, J., Bachrach, C, Jobe, J, Kurtzman, H., & Cain, V. (Eds) (2000). The Science of Self-report: Implications for research and practice. Mahwah, NJ: Lawrence Erlbaum.
14. Trent, S., Voshell, M., Fern, L., Stephens, R. (2007). Designing to Support Command and Control in Urban Firefighting. In the *Proceedings for 13th International Command and Control Research and Technology Symposium*. Bellevue, WA.
15. Woods, D. D., and Roesler, A. (2007). Connecting Design with Cognition at Work. In Schifferstein, H.N.J., & Hekkert, P. (Eds.) *Product Expertise*. Amsterdam: Elsevier.
16. Zachary, W. W., Ryder, J. M., & Hicinbothom, J. H. (2000). Building Cognitive Task Analyses and Models of a Decision-Making Team in a Complex Real-Time Environment. In Schraagen, J.M.C., Chipman, S.F., & Shalin, V. L. (Eds.) Cognitive Task Analysis. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 365-384.