COORDINATION IN URBAN FIREFIGHTING:
A CRITICAL INCIDENT ANALYSIS

THESIS

Presented in Partial Fulfillment of the Requirements for the
Degree Master of Science in the Graduate School of The Ohio State University

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The Ohio State University
2008

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ABSTRACT

This paper describes a critical incident analysis as part of a larger cognitive task analysis to examine coordination and decision making in urban firefighting teams. 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 research however, does not capture decision making in teams where decisions are distributed across interdependent groups and individuals. The current study employs a critical incident analysis to investigate the role of coordination in emergency response operations. The findings revealed a flow of activity in fire incidents that exhibit five phases of activity, coordination and decision-making: alert, initial entry, re-planning, emergency and resolution. Of the four cases analyzed, two exhibited all five and two lacked the emergency phase. The occurrence of coordination breakdowns in the emergency phase suggests the importance of designing systems to support coordination in distributed teams.
ACKNOWLEDGMENTS

First and foremost, I wish to thank my advisor for the confidence and freedom to explore a variety of research interests, for the support and encouragement that made this thesis possible, and for the endless enthusiasm that inspires all of his students.

I thank Stoney Trent for his guidance in research methods during the preliminary stages of the project. I am grateful to Emily Patterson for her continual optimism, and her meticulous patience in correcting my stylistic errors.

Special thanks to Joe and Neil, without whom this project would not exist, and to the rest of the research team for all of their hard work.

This thesis 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. It was also supported by a scholarship from the Natural Sciences and Engineering Research Council of Canada.
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# TABLES OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iii</td>
</tr>
<tr>
<td>Vita</td>
<td>iv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>viii</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Designing Technology to Support Work</td>
<td>3</td>
</tr>
<tr>
<td>1.2 Previous Firefighting Research</td>
<td>8</td>
</tr>
<tr>
<td>2. Cognitive Task Analyses</td>
<td>14</td>
</tr>
<tr>
<td>3. Method</td>
<td>24</td>
</tr>
<tr>
<td>3.1 Initial Contact</td>
<td>25</td>
</tr>
<tr>
<td>3.2 Observations</td>
<td>26</td>
</tr>
<tr>
<td>3.3 Functional Goal Decomposition</td>
<td>27</td>
</tr>
<tr>
<td>3.4 Critical Incident Analysis</td>
<td>33</td>
</tr>
</tbody>
</table>

v
4. Findings .................................................................................................................. 35
   4.1 Alert .................................................................................................................. 36
   4.2 Initial Entry ....................................................................................................... 36
   4.3 Re-planning ....................................................................................................... 37
   4.4 Emergency ......................................................................................................... 38
   4.5 Resolution ......................................................................................................... 39
   4.6 Summary ............................................................................................................ 39

5. Discussion .............................................................................................................. 47
   5.1 Common Ground and Communication ......................................................... 53
   5.2 Future Research ............................................................................................... 61

Appendix ................................................................................................................... 65

List of References ........................................................................................................ 76
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Urban firefighting functions, decisions and information requirements</td>
<td>31</td>
</tr>
<tr>
<td>4.1 Key activities during the phases of Case I</td>
<td>41</td>
</tr>
<tr>
<td>4.2 Key activities during the phases of Case II</td>
<td>42</td>
</tr>
<tr>
<td>4.3 Key activities during the phases of Case III</td>
<td>43</td>
</tr>
<tr>
<td>4.4 Key activities during the phases of Case IV</td>
<td>44</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>The phases of urban firefighting activity with</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>escalation to the emergency phase</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>The phases of urban firefighting activity without</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>escalation to the emergency phase</td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>The influence of cohesive and divergent forces on</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>coordination in distributed teams</td>
<td></td>
</tr>
</tbody>
</table>
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 10,000 rescue personnel responded to the attacks on the World Trade Center (CNN.com, 2001).
These and similar incidents have the potential to create drastic changes to firefighting departments both in terms of organizational structure and response operations. For example, firefighters in New York City today work in a radically different environment than they did before September 11, 2001. In addition to the tragic loss of 343 firefighters and EMS personnel at the World Trade Center site, over 2000 other members left the Fire Department of New York (FDNY) in the post 9/11 environment. “From Sept 11, 2001 to mid-July 2005, 2917 firefighters and officers have retired and 3685 probationary firefighters have been hired and trained; 2059 personnel have been promoted,” (Griffith, 2005). Those that retired were often among the most experienced within the department. This process has created a large experience deficit as the average age and number of years in service has decreased substantially, a situation that has strong impacts on performance in many domains. Extraordinary events such as this 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 the methods and findings of a cognitive task analysis of urban firefighting and to illustrate how this research informs our knowledge of coordination and distributed decision making in complex emergency response operations. In particular, this paper attempts to understand how coordination breaks down in firefighting teams. Coordination breakdowns lead to surprises that create risk to practitioners in uncertain environments. Understanding how coordination breakdowns occur provides an
impetus for designing technology to support coordinative functions necessary in
distributed teams. This study is part of an ongoing research program in
collaboration with The Ohio State University (OSU), the United States Military
Academy (USMA) at West Point and a major metropolitan fire department to
improve urban firefighting operations through technology innovation and training.
The research team involved in this research was led by an assistant professor
from USMA and included several Masters and Doctorate-level graduate students
from OSU. The paper will start with a review of issues that should be considered
when technology systems are designed to support work, followed by an
examination of previous work within the firefighting domain.

1.1 Designing Technology to Support Work

In the face of recent changes to emergency response operations, the
current project provides an opportunity to support coordination and
synchronization activities through technological design. The introduction of new
technology invariably changes the physical work of front line responders, as well
as their cognitive and coordination demands as they learn to operate,
troubleshoot, and manage new systems (Woods & Hollnagel, 2006). Woods and
Roesler (2007) summarize the ways in which technology can impair the cognitive
processes of sharp end practitioners (i.e. those that do the work as opposed to
those who manage the work). In particular, a number of bottlenecks can arise:
knowledge bottlenecks that impede one's ability to recall relevant knowledge;
attention bottlenecks that impair the ability of practitioners to switch attention effectively between different threads of activity; intent bottlenecks that challenge a practitioner's ability to form coherent intentions under uncertainty and multiple conflicting goals; and workload bottlenecks that undermine the ability of practitioners to prioritize work in order to avoid failure at peak work times.

Adding to the problem, clumsy technology tends to hide or miss data at critical periods, hindering responders and key decision makers in the process. When clumsy design is applied to autonomous or semi-autonomous computer agents, it can lead to automation surprises where practitioners are surprised by the behavior of the system relative to their expectations (Woods & Hollnagel, 2006).

A general finding in all variations of emergency response, from military operations to disaster response, indicates that these kinds of technology challenges are the norm, not the exception. Practitioners in these fields are not only experienced in adapting to a unique set of disruptions and surprises, they typically expect them (see Murphy, 2004; Murphy & Burke, 2005; and Burke, et al., 2004 for findings from operational studies of the deployment of robots in search and rescue operations). Evidence of such challenges in urban firefighting has also been documented. For example, in a comprehensive analysis of the FDNY response operations to the terrorist attacks, McKinsey & Company (2002) reported that unreliable radio communications not only severely limited the amount of operations information available to chief officers in the lobby of the World Trade Center towers, it hindered the officers' ability to communicate
evacuation orders to responders. Workload bottlenecks occurred as commanders attempted to identify and adapt to communication disruptions while tracking and coordinating hundreds of members.

The issue of workload bottlenecks becomes critical in coordinated team activity when interdependent members are required to synchronize their activities with each other. Such synchronization depends on four coordination functions: observability, directability, directed attention, and inter-predictability (Woods & Hollnagel, 2006). Observability gives members insight into what others are doing relative to the goals of the team. Observability provides feedback about other members’ work process such as whether they are falling behind or racing ahead, how hard they are working, and if they require assistance. Directability "refers to deliberate attempts to modify the actions of the other partners as conditions and priorities change" (Klein, Feltovich, Bradshaw & Woods, 2005). Directability allows members to influence others as the situation evolves and demands adaptation. Directed attention allows members to re-orient and re-focus on new and changing information that is relevant to the task. Lastly, inter-predictability makes it easier for members to reasonably predict and anticipate the actions of others, and modify their own actions in accordance if need be. (It is important to note that these functions are also critical in human-machine coordinated activity).

Open workspaces, where members are typically co-located and have visual contact with each other, facilitate these coordination functions. The criterion for an open workspace is that members can tell how well others are
achieving their activities relative to their piece of the evolving situation, and is therefore tightly coupled to the observability function (Gutwin & Greenburg, 2002). In particular, members in open workspaces can judge whether others are accomplishing their goals easier or harder than normal. However, physical co-location does not provide the basis of an open workspace. Co-located teams, like distributed teams, may face environments that do not support these functions. For example, urban firefighters within the same smoke-filled room may not be able to maintain direct visual or verbal contact with each other. Such situations provide an opportunity to design technology that support rather than impede coordination of synchronized activity.

The good news is that technology is not inherently bad, despite the challenges in designing systems that support coordinated activity. Good designs can lessen the cognitive demands of practitioners, provide and guide attention to relevant information, and improve performance (Woods & Roesler, 2007). Overall, good designs provide increasing opportunity for practitioners to express their expertise. For first responders this can mean increased life-saving capabilities, response effectiveness and safety.

Many fields have been interested in how technological capabilities can be exploited to aid human work practices. Computer Supported Cooperative Work (CSCW) has addressed "how collaborative activities and their coordination can be supported by means of computer systems" (Grudin, J., 1988). Recently researchers have been interested in how computer systems can support
awareness in distributed group activity and performance (Gutwin & Greenburg, 2002; Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003). Activity awareness focuses on the overall awareness of distributed project work and emphasizes “aspects of the situation that have consequences for how a group works toward a shared goal over time, rather than one person monitoring a complex information array and making real-time decisions” (Carroll, et al., 2003). Breakdowns in activity awareness can be a result of situational, group, task or tool factors. Workspace awareness is addressed by Gutwin and Greenburg (2002) who define it as "the up-to-the-moment understanding of another person's interaction with a shared workspace." Workspace awareness addresses important issues that arise in distributed teams, such as what members are doing, where they are working, and what they are going to do next. The emphasis in the literature is on how difficult awareness is to maintain and support in distributed teams relative to co-located teams, and how this can be addressed when considering designs to support distributed groups. Unfortunately, the prominence of computer software programs (e.g. groupware) and personal computing systems to support work in CSCW limits applicability to emergency response domains where only a small number of practitioners have access to such devices in the field.

Alternately, Cognitive Systems Engineering (CSE) is concerned with supporting natural human performance capabilities through broader design initiatives (Woods & Hollnagel, 2006). 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.

1.2 Previous Firefighting Research

One of the most recognized contributions to understanding decision
making in the context of 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 the 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 assessment is largely dependent on the experience of the practitioner. Situation assessment can be understood in terms of it’s close relationship to sense making.

An analysis of the Mann Gulch fire disaster of 1949, in which 13 firefighters died, has served as the basis for our understanding of sense making in organizations as well as a case study for discovering why organizations unravel and how they can be made more resilient (Weick, 1995). Sense making describes our continual effort to create order in the world and make sense of the past and present. Sense making is about seeing the bigger picture of an evolving situation. Like situation assessment, it is an ongoing process that requires individuals to properly interpret available cues and make rational sense of their environment; individuals are inextricably tied to the context of the situation and match patterns based on their experience base. Errors in sense
making occur when individuals are unable or unwilling to assimilate unanticipated changes because the current situation does not match a familiar experience. Failures in one’s ability to make sense of the world can invariably lead to erroneous decisions.

While the use of situation assessment and sense making concurrently with RPD provide a satisfactory description of how firefighters make decisions in the field, as empirical generalizations they do not describe the specific cognitive work and decision requirements in the domain that can help to inform the design of systems to improve performance. For example, firefighters face such cognitive re-conceptualization issues as: when to make their assessments, in what changing conditions and context they work, what information they use, from where critical information comes 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.

Another body of research has utilized firefighting simulations, or microworlds. These microworlds have been explored as a paradigm for studying team decision making in complex environments in an attempt to bridge the gap between controlled laboratory studies and field or observational studies. In fact, to date, some of the only findings about complex decision making in real-time microworlds have been based on firefighting tasks, which are used because they are deemed sufficiently “complex, realistic, inherently interesting, and readily understood by [non-practitioner] subjects” (Omodei & Wearing, 1995). These
studies have addressed coping with feedback delays (Brehmar & Nahlinder, 2004; Brehmar & Elg, 2005), and resource utilization and situational awareness (Valentine, Wearing, & Omodei, 2007). Unfortunately, a major limitation of these simulation studies is the use of student participants instead of field practitioners. Experienced practitioners are likely to employ different knowledge and strategies in such tasks.

Another shortcoming of the firefighting and decision making literature is that a large majority assume a command structure of decision making whereby one commander, or a single responsible decision maker, is responsible for all necessary actions. Recent endeavors have attempted to overcome this limitation. For example, McLennan, Holgate, Omodei and Wearing (2006) utilized wildfire simulation studies in conjunction with critical incident analysis, structured interviews and observations to examine the effectiveness and processes of Incident Management Teams (IMT) at operational and strategic levels of command. Their findings suggest that highly distributed teams have difficulty managing a common operational understanding and that it is very easy for members to make decisions based on inconsistent information or to engage in unnecessary information gathering and analysis. In the time constrained environment characteristic of emergency response operations, unnecessary information gathering and analysis can have serious consequences as resources are used ineffectively while the situation escalates.
Despite initiatives like these, there still remains a large deficit in understanding how distributed tactical teams in emergency response make decisions. 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. Further, it fails to represent the urgency of an environment where individuals may not have time or may be physically unable to defer decisions to a supervisor and are forced to make critical decisions with consequences to other team members. Therefore it is imperative that an examination of decision-making in emergency response operations takes into account the role of team dynamics. Contributing to a larger cognitive task analysis of urban firefighting to understand coordination demands and decision making in emergency response, this study focuses on an analysis of a corpus of critical incident cases.
Uncovering cognitive activities that are required for successful task
performance means developing a meaningful understanding of the domain at
hand. This is the goal of a cognitive task analysis. Cognitive task analysis (CTA)
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. Urban firefighting operations have a number of defining
characteristics that make CTA findings both innately interesting while at the same
time applicable to other domain operations. First, the structure of urban
firefighting operations is based on the application of pre-planned processes and
procedures that require adaptation to individual incidents. Second, operations
are physically distributed and therefore require more effort to maintain
coordination and collaboration between members than co-located teams. Lastly,
unlike process control systems such as those in nuclear power plants where
practitioners monitor processes on displays, urban firefighting is action-based. Control of an incident and information gathering depends on firefighters “going in” - usually to an uncertain environment where there is always an inherent risk to life.

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 knowledge 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 (for examples of this approach see, Gordon, Babbitt, Bell, Sorenson, & Crane, 1993; Means & Gott, 1988, cf., Roth & Mumaw, 1995).

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 shapes performance and the latter, on how practitioners respond to the inherent demands and challenges built into the domain. Thus a CTA integrates two perspectives, 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. Analytic methods are rooted in understanding the inherent demands of the domain while empirical methods focus on understanding situation-based behavior of practitioners in response to these demands. Formal analytic techniques help to uncover the fundamental characteristics of the domain that give context to the cognitive demands imposed on practitioners (Woods & Hollnagel, 2005; Rasmussen, 1994). Thus, analytic methods provide a framework for understanding practitioner performance in context and are typically conducted prior to more empirical approaches.

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1 Cooke (1986) discusses another approach that integrates both analytic and empirical techniques, but emphasizes the knowledge organization and structure of practitioners as opposed to domain characteristics and situation-based behavior. The techniques used are intended to elicit expert knowledge in the form of facts, rules, procedures, mental models, and heuristics relevant to the domain. This knowledge is typically employed in building expert systems, such as those used in diagnosis and prediction.
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 data collected (Zachary, Ryder & Hicinbothom, 2000). This can be addressed through preliminary domain analysis. Such 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.

Other analytic approaches utilize functional analyses, such as a goal-means decomposition\(^2\). Roth and Mumaw (1995) argue that function-based methods are necessary when empirical analyses of practitioner performance in a task environment are unavailable or infeasible. However, the approach is still relevant to well-known task environments for specifying system requirements to support problem solving and decision-making. These researchers utilized a function-based cognitive task analysis to design system interfaces for a first-of-a-

\(^2\) There are multiple approaches to functional analyses that vary according to a debate over whether they should emphasize more formal requirements versus more practical constraints. (For examples of different approaches, see Elm, Potter, Gualtieri, Roth, & Easter, 2002; Vicente, 1999; Roth & Woods, 1989).
kind advanced control plant. Their 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 provided
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. Their
analysis focused solely on the demands inherent in the domain environment and
what is required to monitor and control the system, excluding the actual behavior
of practitioners within it.

It is important to keep in mind that not all analytic approaches will maintain
a distinction between domain demands and practitioner behavior. The literature
analysis, as mentioned previously, may provide some comprehension of both.
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 in context, 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
focus on understanding situation-based behavior for past (retrospective) or future (prospective) events. Retrospective accounts typically involve verbal reports from practitioners reflecting on a particular experience, or a case study of a critical incident. The goal is to build up a corpus of cases that reveals patterns of knowledge and strategies that practitioners bring to bear, and decisions they face, in order for successful task performance. The challenge is to acquire reports of sufficient detail to detect a meaningful level of behavior driven by the characteristics and constraints of the domain.

Klein, Calderwood, and MacGregor (1991) provide a thorough discussion of the critical decision method (CDM) used in their study of fireground commander decision making. The critical decision method is a retrospective technique that utilizes practitioner recall of specific critical incidents or non-routine incidents. The distinguishing feature of the CDM is that it is augmented with semi-structured interviews guided by probe questions to identify the timeline, potential errors, alternative decision-action paths, and expert/novice performance differences. The purpose of the CDM is to capture the knowledge requirements of real-world decision-making (Hoffman, Crandall, & Shadbolt, 1998). Critical incident methods take advantage of the presumption that non-routine events elicit expertise from practitioners. The CDM and other retrospective techniques are appropriate when the domain places constraints on real-time data gathering. For example, in the aforementioned study of fireground commanders,
researchers found that field observations did not provide sufficient data to inform their analysis (Klein et al., 1989).

Alternately, prospective methods employ some form of observation of natural or simulated environments. Naturalistic observations allow researchers to observe practitioner behavior in their typical environments. However, pragmatic and opportunistic constraints often lead to observations of practitioners in simulated environments such as training exercises and computer simulators. Many CTA methods employ a combination of retrospective reports and observation strategies. Observations can be used to overcome limitations with practitioner recall and to understand the context within which tasks are performed (Flach, 2000). Further, 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”.

These points emphasize the importance of employing multiple methods in any CTA.

CTA techniques have traditionally been developed for, and applied to, research focused on individuals. More recently there has been a shift to using CTAs to examine physically co-located teams. In order to adapt CTA techniques to these teams, researchers have tended to view teams as a single cognitive
entity or mind, focusing on team cognitive processes as opposed to individual cognitive processes (for examples see Klein, 2006; Zachary, Ryder, & Hicinbothom, 2000). Thus CTA methods that are applied to co-located teams and that treat these teams as a single team entity are not substantially different than methods applied to individuals.

Such an approach is not as simple when applying CTA techniques to distributed teams. A CTA of distributed teams must chart the interactions and interdependencies inherent in distributed activity, since interdependency is a defining feature of team coordination. If members of a team are not interdependent, then conducting a CTA is simply a logistics problem; multiple simultaneous can be conducted with each member of the team. Thus a team CTA must track the activities of multiple members, the connections between them, and how they are synchronized.

Synchronization is a particularly important aspect in understanding urban firefighting. For example, hoseline and venting operations must be synchronized in a timely fashion to protect members and extinguish fires. Hoselines serve three important protection functions: protect members that are conducting search operations from fire and heat; protect the interior stairs for retreat; and prevent the spread of fire to the floor by extinguishing any fire extending from lower floors. Hoselines push heat, flame and steam upwards to the floor above, and in the direction opposite the nozzle. Venting should be done immediately before a hoseline is opened on a fire in order to provide an exit for heat and smoke from
the fire building. If venting is done too early, it can feed oxygen to the fire, worsening heat and flame conditions for members in the vicinity and potentially creating a risk for a back draft explosion. If venting is done too late, the heat and smoke can build up on the fire floor, putting members there at risk. In addition, members working above operating hoselines are in direct risk of increased fire conditions. Finally, there should never be two opposing hoselines in operation at an incident. Such a situation can create dangerous operating conditions that can result in injury to members on each team as well as other members working in the vicinity, as heat, flame and smoke are pushed towards them. Thus, mis-synchronizing activities so that members unknowingly work above or opposite an open hoseline represents a coordination breakdown in firefighting teams.

This example of synchronous action highlights the challenge in applying CTA methods to interdependent, distributed teams: it is critical to capture not only coordination, but also synchronization across multiple groups and multiple echelons. Understanding how functions and actions both depend on, and affect, others at the same time is critical. It is also important to understand how members manage these interdependencies and maintain (or fail to maintain) synchronization in the face of disruptions. There is not an easy solution to this problem, but there are key points for employing many of the aforementioned CTA methods to keep in mind. Functional analyses should capture the interdependencies of goals, including goal interactions and conflicts. Observations, whether natural or simulated, necessitate having multiple
observers tracking the behavior of multiple team members. Retrospective reports and critical incidents must incorporate the perspectives of multiple members so that situated behavior can be understood in terms of interactions with others' actions, goals, and responsibilities.

In summary, there is not “one best” approach for a CTA. Conducting a CTA is less about the methods employed and more about the insight that is generated about the domain or practice in question. Multiple techniques that build upon each other provide the impetus for generating this insight. The techniques chosen for any CTA are always 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.
CHAPTER 3

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 access to practitioners and doctrinal publications that allowed us to apply a variety of CTA methods and to encompass both the analytic and empirical approaches. Each approach used built upon, and refined, the findings from the approach that preceded it while at the same time suggesting future trajectories for discovery.
3.1 Initial Contact

In an effort to gain an initial understanding of the domain, our research team reviewed doctrinal publications and departmental circulations such as annual operations evaluations, training curriculum and critical incident reports. Written procedures represent a baseline for understanding practitioner task performance, although actual task performance is usually adapted to the unique demands and challenges of the situation (Suchman 1987; Hutchins1995). While doctrine, written operating procedures, and historical accounts are not completely indicative of work that is actually 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 set expectations for the researcher.

Building on these activities, brief (approximately 15 to 45 minutes), unstructured and informal interviews were conducted with four firefighters, three company officers and five 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. Most 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. In order to supplement data collected in the interviews, the research team also observed daily operations and training exercises.

3.2 Observations

Our team of researchers observed daily operations in firehouses, real incident responses and training exercises over the course of eight days. While shadowing fire chiefs in five different firehouses, the research team observed a fire safety inspection, four fire emergencies, a steam pipe leak, a hazardous material release and multiple false alarms. Additionally, we observed six 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. The incident observations and interviews that were conducted are summarized below.
• Observations:
  
  o Daily Operations in Urban Firehouses (8 days w/ six observers)

  o Incident Responses:
    ▪ 2 x Apartment fires
    ▪ Trash fire
    ▪ Residential basement fire
    ▪ Steam pipe leak
    ▪ 15 x False alarms

  o Training Exercises:
    ▪ 2 Full-scale exercises (high rise & shopping mall)
    ▪ 2 x Table-top exercises (shopping mall & government agency coordination meeting)
    ▪ 2 x Company training exercises (rope training & hose training)

3.3 Functional Goal Decomposition

Based on the findings of the previous activities, the research team began development of a functional goal decomposition (FGD) in order to identify the decisions and information requirements that support the critical functions of firefighting. Interviews were conducted with a fire chief, company officer and firefighter in order to verify a preliminary draft of the functional analysis. In a guided group interview, these practitioners were presented with the analysis and were asked to relate personal experiences that illustrated some of the functions
identified. The current paper utilizes a simplified description of the basic functional categories for framing and understanding the critical incident analysis. (Table 3.1. provides a basic overview of some of the findings).

Firefighting has two goals – save lives and protect property. In order to pursue these two goals, firefighters put themselves at risk for injury or death – a condition that is unique to firefighting and other emergency response domains. This characteristic introduces a third goal to fire departments, to monitor and minimize the risk of injury or death to members, both of which represent failure and define a critical incident. Goal conflicts arise when there are tradeoffs between achieving the three goals. For example, when a fire department forgoes the goal of protecting property in order to minimize risk to firefighters.

Fire departments must perform basic high-level functions in order to balance these goals – manage routes, manage resources, reduce threats, assess situation trajectory, and extract occupants/injured firefighters. These functions are summarized below.

- **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). Managing effective ingress and egress at an incident is essential for supporting other functions by facilitating movement of resources as well as access to threats and life hazards.
• **Manage Resources**: Monitoring, committing, requesting and withdrawing of men, equipment and supplies at the incident. Managing resources depends heavily on the *Assess Situation* function for determining when and where resources need to be added or whether resources should be withdrawn, given the status of the incident. Managing firefighters is particularly critical in supporting the goal of preventing injury and death, and involves tracking and withdrawing responders that may be at risk.

• **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. This is one of the primary functions of firefighting and serves the goal of protecting property. The other functions are typically focused on supporting this function unless there is a life hazard or individual at risk for injury or death.

• **Assess Situation Trajectory**: 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 as the incident develops. This function is captured in the firefighter language of ‘Are we winning or losing?’ Firefighters locally and at command stations are constantly judging the progress of the situation for evidence of containment or control (i.e. winning) versus evidence that the situation is expanding or out of control (losing).
• *Extract Occupants/Injured Firefighters:* Extracting life hazards, occupants and incapacitated firefighters from the incident to reduce injuries and save lives. This is the other primary function of firefighting and serves the goal of saving life. The other functions tend to realign around this function when a life hazard is identified in order to support the immediate goal of saving life, especially when the life hazard is an incapacitated firefighter.
<table>
<thead>
<tr>
<th>Function</th>
<th>Decisions</th>
<th>Information Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manage Routes</td>
<td>What route to take for approaching the incident?</td>
<td>Infrastructure limitations</td>
</tr>
<tr>
<td></td>
<td>Where to lay hoselines?</td>
<td>Traffic patterns</td>
</tr>
<tr>
<td></td>
<td>What are the valid entry/exit paths?</td>
<td>Routes of other responders</td>
</tr>
<tr>
<td></td>
<td>Does a path need to be created?</td>
<td>Environmental conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Occupancy status</td>
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<tr>
<td></td>
<td></td>
<td>Confirmed life hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Condition of roof</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Locations of:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incident</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water sources</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fire or contamination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extensions of fire or contamination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elevators, stairs, doorways, access points</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Obstacles for entry</td>
</tr>
<tr>
<td>Manage Resources</td>
<td>When and where to commit resources?</td>
<td>Progress of search</td>
</tr>
<tr>
<td></td>
<td>When to withdraw or replace resources?</td>
<td>Conditions of building</td>
</tr>
<tr>
<td></td>
<td>When to request resources?</td>
<td>Occupancy status</td>
</tr>
<tr>
<td></td>
<td>Who to designate as a safety team?</td>
<td>Water supply</td>
</tr>
<tr>
<td></td>
<td>Where to establish command post and staging areas?</td>
<td>Resource depletion</td>
</tr>
<tr>
<td></td>
<td>When to request casualty coordinator?</td>
<td>Time units have been exposed</td>
</tr>
<tr>
<td></td>
<td>How to position ladders and pumps?</td>
<td>Current staffing levels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unique apparatus available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Status of uncommitted units</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emergency responder casualties</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structure type and floor plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Street conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Locations of:</td>
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<tr>
<td></td>
<td></td>
<td>Fire or contamination</td>
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<tr>
<td></td>
<td></td>
<td>Extensions of fire or contamination</td>
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<tr>
<td></td>
<td></td>
<td>Life hazards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resources</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power lines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water sources</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building entrances</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other vehicles</td>
</tr>
</tbody>
</table>

Continued

Table 3.1: Urban firefighting functions, decisions and information requirements.
Table 3.1 continued

| Reduce Threat | | Structure type and floor plan  |
|---------------|----------------------------------|
| Whether to attack or contain the fire? | | Conditions in building  |
| Reduce or contain contaminants? | | Type of contamination  |
| Need to set up/establish decontamination? | | Surrounding population  |
| Whether to ventilate or not? | | Weather effects on contaminants  |
| What substance(s) to use on contaminants or fire? | | Locations of:  |
| Where to attack threat? | | - Fuel sources  |
| | | - Fire or contamination  |
| | | - Extensions of fire or contamination  |
| | | - Hoselines  |
| | | - Scuttles and skylights  |

| Assess | Situation Trajectory | | Source of alarm  |
|---------|---------------------|----------------------------------|
| Is it a false alarm? | | Reports from occupants  |
| Cease or continue search for life? | | Presence of heat or smoke  |
| Cease of continue search for fire? | | Fire containment  |
| Where to search? | | 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  |
| | | - Hoselines  |
| | | - Scuttles and skylights  |
| | | - Stairs  |
| | | - Life Hazard  |
| | | - Small rooms  |

<table>
<thead>
<tr>
<th>Extract Occupants/Injured Firefighters</th>
<th>Presence of ladder company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on threat reduction or rescue?</td>
<td>Water supply</td>
</tr>
<tr>
<td>Where to establish a safe refuge area?</td>
<td>Conditions of building</td>
</tr>
<tr>
<td>What is the best method for evacuation?</td>
<td>Occupancy status</td>
</tr>
<tr>
<td>When to deploy a rescue team?</td>
<td>Location of:</td>
</tr>
<tr>
<td></td>
<td>- Fire or contaminants</td>
</tr>
<tr>
<td></td>
<td>- Extension of fire or contaminants</td>
</tr>
<tr>
<td></td>
<td>- Stairs, balconies, fire escapes, elevators, exits</td>
</tr>
<tr>
<td></td>
<td>- Rescue teams</td>
</tr>
<tr>
<td></td>
<td>- Incapacitated or lost occupant or emergency responder</td>
</tr>
</tbody>
</table>
3.4 Critical Incident Analysis

The urban fire department involved in this research project invited the research team to co-operate in a comprehensive review of their critical incident corpus. This fire department conducts thorough investigations, lasting over several months, of all incidents that result in serious injury or death to a firefighter. These investigations incorporate and integrate multiple perspectives from the incident, including a detailed timeline of the activities of multiple units. The cases represent such a high value of thoroughness that a story-generation CTA method is not needed (Crandall, Klein, & Hoffman, 2006). Retrospective critical incident cases limit in the ability to contrast successful outcomes to failures given their focus on events and behavior that led to failure. However, there are sub-stories or indicators of successful behaviors and strategies embedded within the cases even though these incidents met the criteria of requiring a detailed investigation due to injury or death.

A small subset of these cases was made available for a preliminary analysis. Of this small subset, four cases contained sufficient content to use in the analysis. Four cases that were particularly rich in detail were selected for in-depth analysis. While details about individual perspectives were more scarce, they were used whenever possible. The four cases all involved fire incidents, and resulted in five deaths and three serious injuries; two occurred in two-story

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3 The critical incident data used are publicly available and can be obtained through the Freedom of Information Act.
private residential dwellings, and two in two-story commercial buildings. Detailed case summaries are provided in the Appendix.

The functional goal decomposition provided a baseline protocol for analyzing the corpus of cases. This protocol was organized by laying out all of the available known activities and communications of firefighters, officers and chiefs for each minute of the incident timeline. Each activity was analyzed for the function(s) being fulfilled, and decision(s) needed to carry out the activity. Information about the perspectives or mindset of the practitioner and the condition of the incident was also noted where available.

A preliminary review of a single critical incident using the base protocol outlined above, and the initial results of the CTA, revealed that there was a flow to the breakdown of events. This flow can be understood in terms of a pattern of five phases that were characterized by different actions, tempo, coordination and decision-making. These phases were then used with the base protocol as a structuring heuristic to organize the remaining cases. Each of these phases will be described in detail in the following chapter.
CHAPTER 4

FINDINGS

Following the initial review, five fire phases were suggested in the critical incidents: alert, initial entry, re-planning, emergency and resolution. Of the four cases analyzed, two exhibited all five and two lacked the intensity of the emergency phase.\(^4\) A summary of each of the cases is provided below, followed by a detailed description of each of the five phases.

- **Case I**: Cellar fire with coordination breakdown when firefighters unknowingly work above an open hoseline and the floor erupts in flames.
- **Case II**: Cellar fire with coordination breakdown using opposing hoselines.
- **Case III**: Commercial building fire with confusion about the rescue of a lost firefighter.
- **Case IV**: Commercial building with unexpected explosion.

\(^4\) The fourth case lacked a detailed timeline following an unexpected explosion due to complicated and prolonged rescue operations, and the timeline ends in a re-planning phase. However, review of the rescue operations write up suggests that it exhibits the same pattern of four phases as the third case.
4.1 Alert

The alert phase begins when units receive their assignments from the dispatcher. This begins a physical convergence as units move toward the incident. During this phase all units have the same knowledge in the form of standard operating procedures, information provided by dispatch about the location and type of alarm (e.g. automated building alarm, telephone alarm), and information about the building provided by the department database. Decisions during this phase are primarily focused on en route planning - how to get to the incident.

4.2 Initial Entry

This phase commences as the first units arrive on scene and position their apparatus and equipment relative to the fire building. Members initiate standard operating procedures according to the type of building. Initial decisions focus on determining if there is a fire in the building, where it is located, its size and extension, and whether there are any occupants. These decisions support the Assess Situation Trajectory function outlined in Table 3.2. Manage Route decisions remain important as members determine where to position hoselines and how to enter the building, and the Manage Resource function is supported as commanders assign incoming commit units. Decision tempo is low because there are relatively few units on scene and many decisions are dictated by standard operating procedures. During this phase the command structure
predominates as company officers make the majority of the decisions. As more commanders begin to arrive and the command structure builds up, information from on-scene officers is communicated up the hierarchy. Units continue to share common knowledge and expectations, however members start to diverge and become spatially distributed as they spread out and engage in their role activities. This phase captures the “typical” or “normative” procedures.

4.3 Re-planning

The re-planning phase is triggered by a disrupting event or new information that leads to an acknowledgment or awareness that the current operations are inadequate for addressing the incident. A modification of tactical operations requires increased cognitive load as decisions across all functions as members try to adapt to the evolving situation by: making sense of the situation; adding, moving and replacing resources; and determining the best attack strategy. Re-planning puts pressure on communication and coordination activities, as changes must be relayed to all members for success in this phase. In conjunction with increased spatial distribution, these changes create a disrupting pressure on members, however cohesive forces from the command structure enable commanders to centralize control in order for members to be effective and maintain some level of coordination. Decisions continue to be made predominantly by commanders, however there are some decisions by individual firefighters outside of the command structure. The heightened activity
level and increased number of units at the incident lead to some losses of coordination. These losses of coordination typically result from missed communications (information was transmitted but not received) or a lack of communications (important information was not transmitted).

4.4 Emergency

Recognition of an immediate threat of life to members is typically evidence that the situation has escalated to an emergency. This phase is similar to the re-planning phase, with similar decisions and decision tempo as members continue to struggle to gain control of the situation. There is an emphasis on decisions that support the Extract Occupants/Injured Firefighters and Manage Route functions as exiting the fire building becomes crucial to protecting and saving life. This phase represents a fundamental coordination breakdown that is a result of the inability to correct losses of coordination in the previous phase. A fundamental coordination breakdown occurs because members have incorrect or incomplete information about the situation and their activities actually work against each other, often increasing risk to members. As members become isolated (both spatially and in terms of the amount of information they receive) they are forced to make decisions based on their immediate environment. Often, actions are chosen to protect co-located members without knowing the effects of those actions on more spatially distributed members. For example, in Case I, an officer opens a hoseline into the rear of the building in order to protect members
trying to escape as the floor erupts into flames, not knowing that there is an opposing hoseline operating in the front of the building. Decisions are still made predominantly by officers or chiefs, however the command structure has eroded as orders and transfers of information regarding team activities fail to reach the relevant members (specifically the command teams). Decisions are increasingly made by individual firefighters. These decisions often center on a trade-off between threat reduction operations and rescue operations. The desire to save a fallen member contains an emotional element that can supersede role responsibility.

4.5 Resolution

This phase represents the resolution of the situation as the fire is extinguished and/or the member or members have been rescued. This phase typically sees some restoration of the command structure and more coordinated activity as the pace of decisions and activities decrease.

4.6 Summary

In all of the cases, disruption to the initial plan of attack led to re-planning. In the first two cases, changes in the plan of attack were not effectively communicated to all members that were affected by the change. This led to fundamental coordination breakdowns whereby two groups had completely different perspectives of the overall situation. In the first case, members were put
in imminent danger when they unknowingly operated above an open hoseline and the floor erupted in flames. In the second, rescue operations of an unconscious firefighter were greatly hindered when members conducting these operations were put at risk from an opposing hoseline that pushed heat and smoke at them. In the latter two cases, members were injured (the defining quality of a critical incident); however, at no time during the incident was there a fundamental breakdown in coordination. Instead, members were able to repair and maintain effective communication to prevent the type of coordination breakdowns exhibited in the other two cases. Instead of escalating to the emergency phase, the third and fourth cases exhibited two re-planning phases. Tables 4.1 to 4.4 summarize key activities during each phase of the four critical incidents. The phases provide a way to organize the structure of the incidents, and reveals the two distinct pattern that are illustrated in Figures 4.1 and 4.2.
## CASE I: Cellar fire - members work above open hoseline.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert</td>
<td>14:35</td>
<td>- The fire department dispatcher receives a telephone alarm for a fire through 911; initially assigns three ECs, two LCs and a BC.</td>
</tr>
<tr>
<td>Initial Entry</td>
<td>14:38</td>
<td>- Units arrive on scene and see that the fire is in the cellar; initiate standard operating procedures.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- After venting the front picture window, the first arriving LC enters the first floor to perform VES.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The first EC stretches the first line to the front door while the officer enters the first floor to locate the interior cellar stairs. The EC officer reports to BC that he is having trouble locating the stairs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- BC orders the second LC officer to check for rear access to the cellar.</td>
</tr>
<tr>
<td>New Information</td>
<td></td>
<td>- The LC officer reports that there is a clear shot at the fire from the rear.</td>
</tr>
<tr>
<td>Re-planning</td>
<td>14:43</td>
<td>- The BC orders the first EC to take their line to the rear.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The EC officer transmits to the LC performing VES on the first floor that they are moving the hoseline from the front door to the rear. The first LC does not hear this transmission and are unaware that their protecting hoseline has been moved.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The second arriving EC begins to stretch a new hoseline to the front door to replace the first EC’s line.</td>
</tr>
<tr>
<td>Coordination Breakdown</td>
<td></td>
<td>- The first EC opens their hose at the rear cellar entrance to protect members who are forcing the door from flames that are lapping out; this pushes heat and flames up toward the members on the first floor.</td>
</tr>
<tr>
<td>Emergency</td>
<td>14:46</td>
<td>- The first LC officer performing VES on the first floor notices that heat conditions are worsening and orders his members out as the first floor becomes engulfed in flames. All members manage to escape except for the LC officer who is knocked back and becomes unconscious.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Realizing that their officer is missing, several LC members re-enter the first floor to search for him.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The second EC officer at the front door with his hoseline calls for water and enters the first floor. The EC and LC members find the unconscious member and attempt to remove him.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The rear EC repositions their line to the rear door on the first floor and enters with an open hoseline. This opposes the front of the building where members are attempting to remove the LC officer.</td>
</tr>
<tr>
<td>Resolution</td>
<td>14:48</td>
<td>- The front EC extinguishes the fire on the first floor.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The unconscious LC officer is removed from the fire building.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The rear EC shuts down their hoseline and repositions it at the rear cellar door to extinguish fire showing out. They gain entrance to the cellar and extinguish the fire.</td>
</tr>
</tbody>
</table>

EC: Engine Company  
LC: Ladder Company  
BC: Battalion Chief  
VES: Vent, entry and search

Table 4.1: Key activities during the phases of Case I
CASE II: Cellar fire - opposing hoselines.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert</td>
<td>13:37</td>
<td>• Dispatch receives a telephone call for a fire in the cellar of a private dwelling; initially assigns two LCs, two ECs, one RC, one SC, and a BC.</td>
</tr>
<tr>
<td>Initial Entry</td>
<td>13:42</td>
<td>• Units arrive and initiate standard operating procedures.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ECs stretch two hoselines to the front of the building</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The first arriving LC enters the first floor and descends the upper cellar stairs followed by the first EC’s hoseline. The hoseline is opened.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• After reaching the cellar, the LC officer decides to leave. As he crawls up the stairs one of his members following him becomes unconscious on the half landing.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The EC shuts down the hoseline and also leaves the cellar stairs.</td>
</tr>
<tr>
<td>New Information</td>
<td></td>
<td>• Upon exit of the fire building, the LC officer discovers his member missing.</td>
</tr>
<tr>
<td>Re-planning</td>
<td>13:47</td>
<td>• The LC Officer returns to the top of the interior cellar stairs and calls for a hoseline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• BC decides to change strategy and attack the fire from the rear. The second hoseline is ordered repositioned at the rear while the first hoseline is ordered to stay to protect the first flooriona hoseline. He finds his member unconscious and transmits a MAYDAY. Members begin attempts to remove firefighter.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The BC hears this MAYDAY and transmits a second alarm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In the rear, the second EC repeatedly attempts to contact the BC for permission to advance their hoseline into the cellar. The DC orders them to hold their position.</td>
</tr>
<tr>
<td>Coordination Breakdown</td>
<td></td>
<td>• The rear EC opens their hoseline in the rear, and then advances it down the rear exterior cellar stairs and into the cellar. Heat, smoke and flames are pushed toward members operating on the interior cellar stairs.</td>
</tr>
<tr>
<td>Emergency</td>
<td>13:52</td>
<td>• Several attempts are made by different members to remove the unconscious firefighter from the half landing. Members are frequently forced to leave the half landing, and the front hoseline can only be operated intermittently.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rescue operations take approximately 20 minutes.</td>
</tr>
<tr>
<td>Resolution</td>
<td>14:11</td>
<td>• The fire is extinguished in the cellar.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The unconscious firefighter is removed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The EC operating in the cellar from the rear realizes that there is a hoseline operating opposite them and shuts down their line.</td>
</tr>
</tbody>
</table>

EC: Engine Company  
LC: Ladder Company  
RC: Rescue Company  
SC: Squad Company  
BC: Battalion Chief  
DC: Deputy Chief

Table 4.2: Key activities during the phases of Case II
## CASE III: Commercial building fire, lost member.

### Activity

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert</td>
<td>12:28</td>
<td>Dispatch receives a telephone alarm for a fire in the 2nd floor of a mattress store; initially assigns two ECs, two LCs and a BC</td>
</tr>
</tbody>
</table>
| Initial Entry       | 12:34  | • Units arrive and initiate standard operating procedures.  
                    |                     | • ECs stretch a hoseline to the front of the fire building and one to the rear.  
                    |                     | • The first arriving LC initiates forcible entry on roll down gates to the second floor and enter second floor for VES.  
                    |                     | • The first arriving EC brings their hoseline into the fire occupancy on second floor and open it to protect the LC that is searching.  
                    |                     | • The DC transmits a second alarm.  
                    |                     | • The third EC requests permission to operate hoseline into the rear to extinguish visible fire, and are ordered not to hit the fire in the rear because there are companies operating in the fire occupancy.  
                    |                     | • The LC officer decides to pull members off of the fire floor and exits to the second floor stair landing. Upon exiting, he realizes that he is missing one and sends another member to the street to look for him while he checks the fire occupancy.  
                    |                     | • The first EC continues to operate their line.                                                                                          |
| New Information     |        | • The DC decides that members can no longer operate safely inside.                                                                       |
| Re-planning (1)     | 12:55  | • The DC orders all members out of the fire building.  
                    |                     | • After five minutes the first LC officer informs a BC that he has a member unaccounted for. The BC transmits this message to the DC.  
                    |                     | • The LC officer sees a firefighter slumped over, face piece blackened and exhausted. He asks the firefighter, “T--., are you alright?” and receives an affirmative response. He sends the firefighter out to the street and verifies with the BC and other members on the fire floor that his missing member has been accounted for.  
                    |                     | • The DC transmits a third alarm; all remaining members leave the fire floor.  
                    |                     | • Hoselines are operated from the exterior of the building.  
                    |                     | • The LC officer exits the building and searches the street to check on his firefighter that had been missing, but cannot find him. |
| New Information     |        | • The LC officer realizes that he is still missing the firefighter.                                                                     |
| Re-planning (2)     | 13:03  | • The LC officer reports that he is missing a member.  
                    |                     | • A BC orders members to the fire floor to conduct a search for the missing member. They enter the fire floor with a hoseline.  
                    |                     | • The exterior hoselines continue to operate, then are ordered shut down.                                                               |
| Resolution          | 13:14  | • The missing firefighter is found and removed via a stokes basket.  
                    |                     | • All members are withdrawn from the building and the fire is extinguished from exterior water operations.                             |

EC:        Engine Company  
LC:        Ladder Company  
BC:        Battalion Chief  
DC:        Deputy Chief  
VES:       Vent, entry and search

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
</table>
| Resolution          | 13:14  | • The missing firefighter is found and removed via a stokes basket.  
                    |                     | • All members are withdrawn from the building and the fire is extinguished from exterior water operations.                             |

### Table 4.3: Key activities during the phases of Case III
### CASE IV: Commercial building fire - explosion.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert</td>
<td>14:20</td>
<td>• Dispatch receives a telephone call reporting a fire in a hardware store; initially assigns one EC, one LC and one BC.</td>
</tr>
</tbody>
</table>
| Initial Entry | 14:25 | • Units arrive and initiate standard operating procedures.  
  • The SC cuts the roll-down gates to the hardware store and stretches a hoseline to the front of the building.  
  • A second hoseline is stretched to the front, and a third hoseline is stretched to the rear.  
  • The SC and an LC enter the front hardware store to search and find the interior cellar stair entrance. The SC leaves the hardware store and is ordered by the BC to take a hoseline in through the front of the building and hold the stairs, but not go down the cellar.  
  • The BC continues to wait for rear entrance to the cellar to attack the fire.  
  • The rear LCs attempt to gain entrance using various tools. |
| New Information |      | • The BC decides to attack fire from the interior cellar stairs because the rear entry still has not been forced.                        |
| Re-planning (1) | 14:41 | • The BC informs the SC officer to be prepared to make an interior attack.  
  • Another BC then orders the SC to advance their hoseline down the interior cellar stairs. The SC officer instructs members in preparation to advance the hoseline down the cellar stairs. |
| Disrupting Event |      | • An explosion occurs.                                                                                                                  |
| Re-planning (2) | 14:47 | • The DC transmits a second, then a fourth alarm.  
  • Members begin making their way out of the collapse area, or are assisted by other members in getting out.  
  • Portable ladders were raised on the exposure #1 and #2 sides to facilitate members’ escape from the second floor and roof  
  • The DC gains control of the handie-talkie and orders the roll call for all units. The DC becomes aware that one member is trapped in the cellar and two are buried under the rubble of a collapsed wall.  
  • A SC is assigned to rescue a firefighter that is trapped in the cellar.  
  • The DC orders units to search the collapse area for the missing members.  
  • Members continue to operate hoselines and Hi-Expansion Foam to control the fire during rescue operations. |
| Resolution     | 15:55 | • All injured members are transported to area hospitals.                                                                               |

EC: Engine Company  
LC: Ladder Company  
SC: Squad Company  
BC: Battalion Chief  
DC: Deputy Chief

Table 4.4: Key activities during the phases of Case IV
Figure 4.1: The phases of urban firefighting activity with escalation to the emergency phase.
Figure 4.2: The phases of urban firefighting activity without escalation to the emergency phase.
CHAPTER 5

DISCUSSION

This study examined a critical incident analysis as part of a larger CTA in order to understand coordination, and coordination breakdowns in particular, within the context of decision making in urban firefighting. The findings emphasize that coordination and decision making are highly interdependent and that an understanding of decision making requires investigation into the conditions of group coordination.

The analysis found that during coordination breakdowns, practitioners were still able to make decisions that were appropriate given their immediate environment and that can be judged as inappropriate only in light of the overall situation and activities of others. This reinforces the point of view that the ability of firefighters to work effectively and safely depends critically on their ability to coordinate activities. Even typical incidents require individual units and teams to anticipate and confirm the activities of others to successfully operate in a fire.
The description of hoseline positioning and venting operations in a previous chapter highlighted the importance of the ability of team members to effectively coordinate activities. The analysis revealed that many of the critical incidents examined were brought on or exacerbated by uncoordinated operations such as: two hoselines operating in opposition of each other, members unknowingly working above open hoselines, or unintended venting operations that caused increased heat and fire conditions. What is particularly interesting is that two of the four incidents analyzed did not escalate into an emergency phase despite an evolving situation that resulted in a firefighter injury or death. In these cases, the commanders were able to repair losses of coordination and maintain an effective command structure before a complete breakdown could occur. This further emphasizes the importance of supporting coordination activities in the design of technology to support firefighting and other emergency response situations.

Team coordination in urban firefighting can be understood as being mediated by the effects of cohesive and divergent forces on the ability of the team to plan and launch their attack, as well as reduce risk of separation or isolation of members. Cohesive forces emerge from domain activities that drive coordination by facilitating alignment and continuity in distributed teams. They create the potential to synchronize activities, and maintain common ground and other coordinative functions discussed by Klein, et al. (2005). Divergent forces hinder coordination and arise from characteristics of the incident response that
have the potential to fragment the team and disrupt coordinative functions. In distributed tactical teams like those found in urban firefighting, the physical distribution of the team relative to the terrain (physical properties) of the fire site provides one of the major sources of cohesion and divergence. Figure 5.1 illustrates the relationship between cohesive and divergent forces to team coordination.

The five phases of activity observed in the critical incident analysis represent a heuristic for describing how forces of cohesion and divergence affect coordination in urban firefighting teams within the context of an incident response. Cohesive forces originate from the physical convergence of units at an incident in order to launch their attack on the threat. This physical convergence provides the first opportunity for members to align their goals and strategies. Cohesion within the team is reinforced as the command structure starts to build up and direct incoming units that are arriving on the scene. Here, units are brought into an understood plan of attack and hierarchical structure according to well-practiced procedures. Cohesion is initially strong in the command structure due to a relatively small number of easily visible members that are minimally dispersed. Further, communication lines are effective since minimal communication is required as a few members carry out well-practiced roles.
Figure 5.1: The influence of cohesive and divergent forces on coordination in distributed teams.
As the incident progresses disruptions may occur externally as a change in the threat is posed or new information about the threat is gathered, or internally to the incident response team as additional units arrive or resources fail. External disruptions typically require a change in tactics or strategy. For example, an initial attack plan may focus on attacking a fire from the rear, however if entrance to the rear cannot be forced open to allow a hoseline through, the incident commander may decide to change strategy and attack the fire from the front. The external disruption may be a result of new information (e.g. inability to access the building from the planned entrance) or it may be a disrupting event (e.g. an explosion). The figures in the previous chapter illustrate where these disruptions occurred in the pattern of phases observed in the critical incident analysis.

Internal disruptions challenge the ability of the team to maintain a cohesive command structure by creating discontinuity in team members' perspectives or understanding of the incident. Like external disruptions, internal disruptions may also be a result of new information (e.g. a missing firefighter) or a disrupting event (e.g. communication failure). As more units arrive and begin to carry out their various roles and responsibilities they become spatially distributed. This physical distribution of resources creates a risk for fragmentation in the team, and provides the initial source of divergence in the incident response. Physical distribution decreases the visibility of members and consequently, increases the risk of lost or missing members.
Physical distribution also increases communication demands. This increase in communication demands creates a potential for disruption in two general ways: members may not transmit relevant information to others, or members may transmit relevant information that is not received by those intended. In both cases, members miss relevant information about the incident. Building on the example above, this could happen if the incident commander orders the rear units to cease operations so that the front units can advance an open hoseline into the building instead, but the rear units don’t hear this order.

Such communication challenges combined with physical distribution increases divergence of team members even more as members develop an understanding of the situation that is inconsistent with others’ assessment. Further, when missed communication is coupled with an external disruption and the need to change tactical operations, the team becomes vulnerable to a coordination breakdown. To illustrate with our example, the rear units, upon gaining entrance to the rear (because they didn’t hear the order to stop) might advance an open hoseline into the building (according to the original attack plan) opposing the hoseline of the front units and putting both themselves and the opposing units at risk.

The likelihood of both external and internal disruptions in urban firefighting is high. Every fire is unique and requires different response attributes. Regardless of the communication and other infrastructures employed, disruptions that challenge coordination will occur. However, teams can prevent coordination
breakdowns. The risk for coordination breakdowns increases, not because there are disruptions, but because disruptions are not well handled. Coordination breakdowns are a result of uncorrected misunderstandings about what each member or group is doing relative to others that are inherent in an incident response. When members can correct misunderstandings, for example, by detecting and repairing communication disruptions, coordination breakdowns can be averted. Common ground is required to help groups correct misunderstandings and therefore avoid coordination breakdowns. Common ground is referred to as “the pertinent mutual knowledge, mutual beliefs and mutual assumptions that support interdependent actions in some joint activity” (Klein et al., 2005). The critical incidents capture what it means for distributed tactical teams to maintain or lose common ground in the face of disrupting events.

5.1 Common Ground and Communication

The cohesive and divergent forces can be understood in terms of their effect on common ground. Cohesive forces facilitate common ground through shared knowledge about the roles and functions of each member, the current incident, and the goals of the team, that allow teams to recognize and repair misunderstandings. The ability to effectively maintain common ground is illustrated in Case III and Case IV. These cases did not progress into the emergency phase despite the existence of multiple disrupting events. In the face
of these pressures the teams were able to re-establish and readjust common
ground by correcting misunderstandings among members. The command
structure provides the vehicle for maintaining common ground among all
members as commanders integrate information gathered from different
perspectives. The command structure then uses this information to plan and
communicate operational tactics to the team. Divergent forces impede the ability
of the team to monitor, detect, and repair misunderstandings when disruptions
occur. This may be a result of the physical characteristics of the terrain that
create barriers between members or to unanticipated communication
interruptions. Divergence places increased demands on common ground and
other coordinative functions, as more effort is required to correct mistaken beliefs
about the current status and tactical operations of the incident.

Not surprisingly, the coordination breakdowns identified in the critical
incident analysis co-occurred with loss of common ground. Losses of common
ground can occur when: team members lack experience, have access to different
data, do not understand the rationale for orders made by a supervisor, are
ignorant of different perspectives, experience unexpected loss of
communications or are unable to repair losses of communication, or cannot keep
track of who knows what (cf., Klein, Armstrong, Woods, Gokulachandra, & Klein,
2000). Examples of losses of common ground occurred frequently in the critical
incident analysis, largely because of the structure and nature of their distributed
work. Although members within a single unit (e.g. truck or engine company) are
typically familiar with working together, members across units are not, especially at larger incidents where units respond from further geographical locations. The distribution of members has a two-fold effect on common ground: members have access to different cues and perspectives of the incident, particularly in the form of information about the threat (e.g. smoke and heat) and building characteristics. At the same time, they are unable to determine the perspective of other members that they are not in contact with. This drives the need for communication between distributed members. When these communication demands are coupled with the inability of members to monitor confirmation of messages and confusion over who knows what, common ground disintegrates and coordination surprises occur (Klein et al., 2005).

Within the context of urban firefighting, maintaining common ground among distributed members depends primarily on the ability of individuals and sub-units to communicate effectively with one or more other individuals or sub-units. Firefighting operations are such that units arriving on scene typically divide into two or three sub-units responsible for certain activities required in different areas of a fire building. Thus, the firefighting team is comprised of many distributed sub-units, where distribution is dependent on the situational characteristics of the fire building and size of the response. Co-located sub-units frequently must communicate with those in different rooms, on different floors, or even outside of the fire building. The primary means of communication is via individual radios. The fire department involved in the current study utilizes a
single-frequency radio called a “handie-talkie”. Every firefighter, officer, and chief carries this handie-talkie, and every member is on the same frequency; all units are interconnected.

When issues of communication challenges arise, one proposed solution typically employs complete inter-connectivity. The argument typically goes: if everyone can talk to everyone else and have the same information as everyone else, then coordination would be solved. The radios used by this fire department demonstrate why this approach fails. If one considers that a relatively small incident involves approximately five units, and each of the five units carries an officer and five firefighters, one can imagine how quickly radio traffic can become cumbersome. Members must communicate within their own unit, to other units, and to the incident commander. Communications between tactical or strategic working groups are forced onto one network for everyone to hear, even though they may only concern a small number of individuals. This clutters critical coordination loops among working groups, discourages some communications in favor of network traffic discipline and creates bulk to firefighters. Further, members attempting to transmit a message override any other message that is being transmitted at the same time, possibly preventing critical information from reaching the intended person. It is not surprising then, that many of the critical incidents revealed coordination breakdowns as a result of heavy radio traffic and ineffective communication.
Patterson, Watts-Perotti, and Woods (1999) describe the voice loop system employed by mission controllers at NASA to support coordination between multiple, spatially distributed groups:

“Controllers use the voice loops to directly communicate with other personnel in mission control. More importantly, however, controllers use the voice loops to remain aware of the activities of other controllers and mission events in related shuttle subsystems. Controllers continuously monitor approximately four voice loops while directly communicating on a primary loop. By being aware of events when they occur, they can synchronize their activities with other controllers and with the actions of the astronauts. If something that is reported on the loops does not match their expectations, they can direct their attention to that thread of conversation and investigate what the deviations are and how their own activities might be impacted.” (p. 353)

This example highlights how technology can be used to support coordination among teams without loading up on bandwidth and without complete interconnectivity.

Supporting effective communications poses one of the most visible challenges in urban firefighting and still requires further investigation and inquiry into possible solutions. One proposal is to employ the use of multi-channel communication systems that would allow command teams (i.e. fire chiefs and their aides) to monitor and interact on multiple echelon networks (Trent, Voshell, Fern, & Stephens, 2008). The system would utilize aerial and retransmission platforms that reduce the interference of physical structures. Individuals on the networks would be allowed to switch between them through a network toggle using a single handheld device. Regardless of the infrastructure adopted, it is important to realize that communication challenges will always arise and
challenge team coordination. Further, effective communication systems are not the only opportunity for aiding urban firefighting; the larger overall problem of supporting coordination must still be addressed.

5.2 Designing to Support Coordination

The findings from the critical incident analysis raise questions about how to support coordination in urban firefighting and other emergency response operations. Given that challenges to team coordination typically arise during the re-planning stage of operations, one possibility is to reduce the amount or extent to which re-planning is required. Though it is evident that both external disruptions to the physical conditions of the incident and internal disruptions that affect the team are inevitable, information can be made available that can prepare urban firefighting departments for the former type of disruptions. A current project underway with the fire department studied, is attempting to make building information from the City Department of Buildings available to the department. Such information may alert firefighters to potential hazards such as hazardous materials, lightweight building construction, or contents that burn at high temperatures. It may also provide critical information about floor plans, renovations, and available entrances, stairs cases, and fire escapes. Often firefighters arrive with little building construction information and must determine critical building characteristics in low visibility conditions. Though it was not indicated in any of the critical incidents examined, verbal reports from firefighters
suggest that surprises in building construction (e.g. covered exits and stairs, poor construction) put them at extremely high risk for injury. Other critical location or area specific information that would also be valuable prior to a response include location and status of hydrants and the existence of potential hazards.

The in-vehicle system observed in this study for collecting and disseminating building- or location-relevant information was limited to 160 characters. The constraint is a result of the limited bandwidth copper wire network that was utilized in the 1900s for relaying alarms from manual pull boxes. Though not investigated within the scope of this study thus far, it is likely that other major urban fire departments work under similar constraints. Modern communications architectures should support a graphical interface that make pertinent building and location information available en route to the incident, in addition to dispatcher information concerning the current incident (e.g. alarm type) and response size (i.e. number and type of units). Although this kind of information does not prevent the chances of disruptions, providing critical building information en route to an incident can better prepare units for their initial attack strategy so that re-planning activities occur less frequently and place less demands on team coordination.

Addressing the issue of tracking members provides another opportunity for supporting firefighting teams during incident response. Though it is difficult to estimate, the occurrence of missing or lost firefighters may be relatively high, and interviews with officers and chiefs indicate that firefighters are reluctant to ask for
help until they are in imminent danger and little time remains to find and rescue them. Often, firefighters may overestimate the amount of air they have left, be unable to accurately determine heat conditions due to their protective gear, or be unaware that they are lost. Further, a firefighter can become immediately incapacitated if his face piece is accidentally dislodged and he inhales carbon monoxide or other noxious materials. The CTA revealed that members who become separated from the rest of the team are at increased risk of becoming trapped, running out of air, and falling unconscious. The only automated alerting device that the current fire department employs is designed to identify firefighters who have been motionless for a pre-determined amount of time, and is subject to man false alarms. Firefighters are habituated to the sound of this alarm and it is generally viewed only as a distraction. Commanders therefore rely primarily on verbal communication to locate and identify missing firefighters. A device that integrates and provides situational alerts (i.e. heat, smoke, remaining air, injured or lost firefighters) to firefighters and commanders could greatly assist in tracking and removing members. Such a device could also take advantage of GPS technology to enhance tracking ability, however, it should not be the sole method employed as reception is often hampered by obstructions and may be unreliable, particularly in high-rise buildings. Overall, any system that aids in providing firefighter-tracking information would greatly enhance the team’s ability to anticipate and adapt to events that put firefighters at risk and challenge team coordination.
These design concepts provide hypotheses about what may be useful artifacts to support practitioners in the field (Woods, 1998). While still in preliminary stages, these proposed technologies are derived from field research and guided by the functional demands of practice in order to shape cognition and collaboration more effectively. In proposing these designs to support coordination in urban firefighting, one must keep in mind the physical constraints of the domain.

Challenges to cognition and coordination are tightly coupled to the inherent physical challenges practitioners face. Physically distributed and often interdependent teams must be able to communicate various kinds of information without increasing the physical and cognitive demands on the already heavily burdened practitioners. Effective designs must address these physical difficulties as well as the attentional and workload demands imposed on firefighters. These suggestions are tentative models that are open to revision and testing as relationships between they physical nature of the work, technology change, and cognition/collaboration evolve. Future research in the project aims at testing designs based on the above recommendations in staged world studies to see if they meet these challenges.

**Future Research**

The use of multiple CTA methods has proven valuable for uncovering the fundamental demands of urban firefighting and the behavior of practitioners in
response to them. In particular, the critical incident analysis has highlighted the importance of coordination in interdependent, distributed teams. The results must be regarded with some caution, however, as the analysis included only four cases. Investigation of a larger corpus of incidents will provide more insight into the prevalence of the observed patterns of activity. In addition, given that all of our data has been collected with one major urban fire department, these findings must be verified elsewhere to ensure sufficient external validity. In particular, studies involving larger-scale incidents could test the generalizeability of the findings to other emergency response operations. Given the relatively contained nature of urban firefighting, it is possible that large-scale operations, such as those observed in response to natural disasters, do not exhibit the influence of cohesive and divergent forces.

Despite these limitations, the current project provides insight into future trajectories for discovery. In addition to a more in depth analysis of critical incidents, next phase of this project involves developing representative large-scale emergency response scenarios in conjunction with a cadre of fire officers responsible for developing full-scale exercise for department training purposes. Narratives will be developed from the observations and critical incidents of this study, as well as those collected from fire investigations in other cities, to use as scenarios for improving our current understanding of dynamic decision-making and coordination in firefighting. Natural evolutions of this work will utilize staged world studies to test this understanding and for leveraging our findings in the
development of designs for support tools. Staged world studies provide investigators with some control over the type of domain problems introduced to practitioners through the scenarios in which they are instantiated (Woods & Hollnagel, 2006). This facilitates observations of practitioner response to particular problems. However, unlike naturalistic observations, they provide some recourse for repeated observations.

Additionally, the critical incident results provide feedback that tests and indicates where to make advances in the functional goal decomposition (for example, see this mutual influence across empirical and analytic CTA methods in Roth and Woods, 1988). In its current form, the functional goal decomposition does not sufficiently represent the interdependent nature of particular functions, nor does it highlight all of the goal conflicts that can occur. The results from the current analysis indicate that these characteristics are prevalent in urban firefighting, and clarifying the conditions under which they occur may provide more insight into how to support carrying out these functions in pursuit of individual and team goals. Lastly, the information requirements outlined in the functional goal decomposition that support decision making deserve further examination in the design of information support systems. It is likely that these information requirements point to key characteristics of such systems, and therefore should be understood further within the context of incident response operations.
The CTA methods employed in this study have been effective in adding to an understanding of the difficulties that are overcome when firefighting teams perform well. Specifically, the methods have highlighted the importance of managing coordination challenges that arise in distributed tactical teams. Further, these findings have identified important opportunities for improving team performance through design recommendations that address the physical constraints and functional goals of this particular domain.
APPENDIX

CRITICAL INCIDENT SUMMARIES
Case I

In the month of November, a metropolitan Fire Department’s Dispatch Communications Office received a call from a 911 Operator reporting a structural fire. The Dispatcher transmitted an address at 1434 hours based on the information received, and Fire Department units responded. This information turned out to be for an incorrect address.

The 911 reviewed the initial tapes and at 1434 hours informed the Dispatch Communications Office of the corrected address. The Dispatcher then transmitted a new address at 1435 hours. There was a delayed response to this fire of one minute eighteen seconds because of the incorrect information.

On arrival, units found a fire in the cellar of a two story, peak roof, non-fireproof, detached private dwelling approximately 20 feet wide by 40 feet deep. Heavy black smoke was seen venting from the chimney, windows and other openings on all floors of the building. Standard operations were initiated. The first Engine Company to arrive stretched the first hoseline to the first floor at the front door and charged it. They then repositioned their hoseline to the rear exterior entrance after hearing that there was access to the fire from the rear cellar exterior entrance. At the same time a second hoseline was ordered stretched to the first floor entrance by the Acting Battalion Chief to replace the first hoseline, originally positioned at the front door. The second Engine Company stretched this second hoseline to the front door but charged and
advanced into the first floor only after the fire engulfed the entire first floor, injuring a Lieutenant.

The first due Ladder Company gained entry to the first floor and initiated ventilation, entry, and search (VES) of this area. The second due Ladder Company was ordered by the Acting Battalion Chief to the rear cellar exterior entrance for VES. The unit experience delayed entry due to fire venting from the rear door and difficulty in forcing entry.

Another Ladder Company officer and two firefighters (Inside Team) were conducting the primary search on the first floor when a sudden increase in heat conditions from an open hoseline in the cellar forced them to begin exiting the fire area. While they attempted to exit, the first floor erupted entirely in flames and fire vented out the first floor windows. The Lieutenant of this Ladder Company became entangled in the frame of a large screen television located in the living room area. He was discovered semi-conscious approximately 8 or 9 minutes after his arrival with extensive second and third degree burns.

The second arriving Engine Company found the unconscious Lieutenant while advancing their hoseline from the front entrance approximately one minute from the time the first floor was engulfed in flames. For a short time, a hoseline from the rear was operated on the first floor in opposition to this hoseline. Several members removed the Lieutenant to the street. The removal effort took approximately one minute.
In the month of January, a metropolitan Fire Department Dispatch Communications Office received a telephone alarm reporting a fire in a private dwelling. The Dispatcher assigned a full first alarm assignment due to the number of phone calls received. The first arrive Engine Company transmitted a confirmation on arrival for a fire in a two story private dwelling at 1340 hours. Fire department standard operating procedures for a fire in a private dwelling were initiated.

The fire building was a two story detached, peaked roof, private dwelling. The building was approximately 25 feet wide by 50 feet deep. The fire was in the cellar of this building. A Ladder Company Firefighter was discovered unconscious on the half landing of the stairway leading up from the cellar approximately eight minutes after his arrival on scene. When he was found, his helmet was not on his head and his Self Contained Breathing Apparatus (SCBA) face piece was off his face. The Firefighter was in the process of exiting the building directly behind his officer when he inhaled toxic and highly heated gases, which caused him to lose consciousness.

On exiting the building, the Firefighter’s officer noticed that he was missing and transmitted a MAYDAY. The Ladder Officer then re-entered the building with another member in search of him. They found the firefighter unconscious on the
stairway landing within one minute after he was first noticed missing. The Ladder Officer then transmitted a second MAYDAY for a member down on the stairs.

The Ladder Company Officer attempted to remove the firefighter but was unable to do so. The removal operation continued for approximately 22 minutes until the firefighter was removed to the street at approximately 1410 hours. A high heat and heavy smoke condition from an opposing hoseline as well as the absence of a hoseline between the fire and the rescue operation hindered the removal operation of the firefighter.
In the month of December, at approximately 12:28 hours, a metropolitan Fire Department Dispatch Communications Office received a telephone alarm of fire. The caller reported that there was smoke coming from the second floor of a commercial building.

Units of the Fire Department were dispatched. The initial response included three engine companies, two ladder companies, and one battalion chief. A Ladder Company was just one block away and arrived at 12:31 hours. Seeing smoke issuing from the second floor windows, the Ladder Company’s lieutenant transmitted a confirmation of fire. Fire department operations were initiated. Engine companies stretched and operated hoselines. Ladder companies started to vent and search for fire.

The building was a two story commercial structure with stores on the first floor and a furniture storage occupancy on the second floor. The building was approximately 52 feet wide and 87 feet deep.

A short time after the first arriving Ladder Company began operating in the fire occupancy, the lieutenant could not account for one of his firefighters. The lieutenant sent the ‘can man’ downstairs to search for the missing firefighter while he, himself, tried to locate the missing firefighter on the fire floor. Shortly thereafter, the lieutenant believed he had located the firefighter and made an announcement to that effect on his handie-talkie. But the smoke conditions were
heavy and visibility was poor. The member that he thought was his missing firefighter was, in fact, someone else.

A subsequent search in the street revealed that the firefighter was still missing. The lieutenant notified the Deputy Chief. The Communications Coordinator (a battalion chief), ordered the Rescue Company into the building to search. After eight or nine minutes, they located the missing firefighter. He was unconscious. The Rescue Company transmitted an “Urgent” message on the handie-talkie. Cardio Pulmonary Resuscitation was initiated, and the unconscious firefighter was removed to the street.

Emergency medical service and other firefighters rendered first aid to the unconscious firefighter enroute to the hospital.
Case IV

In the month of June, at 1420 hours, a metropolitan Fire Department Dispatch Communications Office received a telephone alarm, reporting fire in a hardware store. The dispatcher assigned one Engine Company, one Ladder Company and a battalion chief to respond at 1421 hours.

A Squad Company, which had taken up from a hazardous material incident in the area, received a verbal report of a building fire. The Squad Company notified the dispatcher and investigated. Arriving at the scene, the Officer of the Squad Company investigated and discovered that the location had a different address than the one assigned by the dispatcher. He notified the dispatcher and initiated standard firefighting procedures.

The fire building was a two-story, non-fireproof structure, approximately 20 feet wide by 55 feet deep. A hardware store occupied the cellar, first and second floors. The cellar was used for storage and the second floor contained office space and storerooms. The fire building was attached on the exposure #2 side to a similarly constructed building. This was a two-story non-fireproof structure, approximately 51 feet wide by 60 feet deep, irregular and triangular in shape. The exposure #2 building was occupied on the first floor and cellar by the hardware store. The second floor of the building was used as a dwelling containing two apartments. The fire building and exposure #2 were interconnected at both the first floor and cellar levels. An opening of
approximately 27 feet had been made on the first floor, joining the two stores. A 2 1/2-foot wide opening through the foundation wall had been made in the cellar. This opening was protected by a sliding metal fire door, which did not function because it was blocked open with a piece of wood.

The Squad Company stretched a 2 1/2-inch hoseline to the front entrance of the hardware store and initiated forcible entry. Other units arrived and began operating at their assigned locations. The front entrances were forced open. The Squad Company stretched their 2 1/2-inch hoseline through the main entrance of the hardware store. Hoselines also were stretched to the rear exterior cellar entrance. The location of the fire was in the cellar, with possible extension up into the stores. The degree of fire involvement could not be immediately determined. Smoke and heat were found at the top of the cellar stairs in the exposure #2 building.

Two 2 1/2-inch charged hoselines were stretched into position. The Squad Company positioned one hose in the vicinity of the interior stairs to the cellar. An Engine Company positioned the other hose in the vicinity of the rear exterior entrance to the cellar. Back-up hoselines were also stretched to both locations. The first assigned Battalion Chief believed that the attack on the fire via the rear exterior cellar entrance would provide the safest path. Lines were in position, but due to difficulties in gaining entry, no water was placed on the fire for approximately 25 minutes preceding the explosion.
The door assembly at the rear exterior entrance to the cellar was very well secured in an unconventional manner. Units ordered to gain entry used conventional forcible entry tools, a rabbit tool, a power saw equipped with a metal cutting blade, and a Hurst tool in a prolonged effort to open this door. After 14 minutes of effort, a ladder company had partially opened this door approximately 18 inches. The explosion occurred soon afterwards.

At approximately 1447 hours, a powerful explosion occurred in the cellars of both buildings. The force of the explosion ejected some fire department members out of and away from the building. One wall crumbled to the ground, completely burying two firefighters. Both succumbed to their injuries. Another firefighter was partially buried under the same collapsed wall and sustained serious injury, while a lieutenant who had been operating at the rear exterior entrance to the cellar was injured and knocked unconscious as a result of the explosion. Both of these firefighters were hospitalized in critical condition.

On the first floor of the exposure #2 building, a firefighter was thrown down the stairs into the cellar by the force of the explosion. He called for help over his handie-talkie radio. All efforts to reach and rescue this member were unsuccessful. The firefighter succumbed to his injuries.

A rapidly expanding fire condition in the cellar, first and second floors of the fire building and in exposure #2 followed the explosion and collapse. The threat and the occurrence of a secondary collapse necessitated removal of all firefighters from the front of both buildings for a period of time. Many other
firefighters were also injured in the explosion. They were removed to areas of safety, stabilized by EMS and transported to area hospitals.
LIST OF REFERENCES


BBC News. Mexico explosions kill dozens. 27 September 1999.


