

Improving Interruption Recovery in Human-Supervisory Control (HSC)

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Interruptions have negative effects on the task performance in modern work environments. These negative effects are not affordable in tasks in which decisions are time-critical and have a life-critical nature. Human-supervisory control (HSC) tasks in time-critical settings such as mission command and control and emergency response are especially vulnerable to the negative effects of interruptions since supervisors in these settings are prone to frequent interruptions which are valuable source of information and hence cannot be ignored and consequences of a wrong decision in these settings is very costly because of their life-critical nature.

To address this issue, this thesis investigates an activity-centric design approach that aims to help team supervisors in a complex mission control operation to remain aware of the activities that most likely would affect their decisions, while minimizing disruption. An interruption recovery assistant (IRA) tool was designed to promote activity and situation awareness of a team of UAV operators in a representative task. Initial pilot studies showed a positive trend in effectiveness of the IRA tool on recovery time and decision accuracy.

This thesis explores alternative design approaches to validate the effectiveness of an interruption recovery tool that enable mission commanders rapidly and effectively regain the situational awareness after an interruption occurs in the mission environment. This thesis overview these design approaches and present results from a series of formative evaluations of our prototype designs. These evaluations were conducted in an experimental platform designed to emulate futuristic semi-autonomous UAV team mission operations.

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Elaheh and Mohammad; my brothers, Farzin and Ardalan; my nephew, Armin and my dog,
Panbeh.

Dedication

I dedicate this thesis to my wife, Elmira; and to my parents who supported me all these years.

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List of Acronyms

AOI	Area of Interest
HSC	Human Supervisory Control
IAI	Interruption Assistance Interface
IR	Interruption Recovery
IRA	Interruption Recovery Assistance
JSTARS	Joint Surveillance and Target Attack Radar System
MCI	Mission Commander
RAD	Remote Assistance Display
UAV	Unmanned Aerial Vehicle Interface
MSD	Mission Status Display
MD	Map Display

Chapter 1

Introduction

Collaborative and communication technologies are rapidly improving and are becoming more functional in providing coordination support for supervisors in time-critical work environments such as military command and control, air traffic control and emergency response. However, these technologies, along with other common human-human communications in these environments, make people more vulnerable to frequent interruptions, especially when interacting with computers. For example, while real-time collaborative tools such as E-mail notifications, instant messengers, voice chats or even phone calls are valuable collaborative tools and may be the source of valuable information, they can also be disruptive due to constantly changing circumstances in time-critical settings. However, they can also negatively affect the work performance of the interruptee.

Previous research shows that the effects of interruptions vary depending on people's abilities or the type of task, for instance, although in some tasks interruptions may increase the performance by decreasing boredom or increasing arousal (Speier et al., 1997), in tasks with high cognitive demand, such as command and control, interruptions may increase stress, anxiety, and annoyance leading to reduced efficiency on a primary task (Latorella, 1998; Bailey et al. 2001). Empirical studies have shown that interruptions can increase error rates in individual task activities (Van Bergen, 1968; Kirmeyer, 1988; Cellier & Eyrolle, 1992; Czerwinski et al., 2000). Moreover, interruptions can also cause coordination problems, work

overload, and time pressure in team-based activities (Reder & Schwab, 1990; Jett & George, 2003).

Failure to recover from an interruption in a life-critical task may cause a serious tragedy. For example, a Northwest airplane crashed because the flight crew forgot to finish the preflight checklist after they were interrupted by an air traffic control operator (NTSB, 1988). Failing to resume the preflight checklist after the interruption caused the crew to skip checking the aircraft's flaps which were in the wrong position and caused the airplane to crash after the take off. The consequences of an incorrect decision could be even more costly in other settings like emergency response, command and control and nuclear power plants that are more vulnerable to the negative effects of interruption as will be discussed in next section. In this thesis, I investigate the problem of interruptions in time-critical work environments and the interruption recovery techniques to help supervisors in such environments recover from interruptions as efficiently and as effectively as possible.

1.1 Motivation

Researchers recognizing the need to mitigate the negative effects of interruptions in different work environments have taken two general investigative directions in doing so:

1. *Pre-interruption support*: Research that investigates the effects of interruptions and that studies preventive measures to control the occurrence of interruptions (e.g., Patterson et al., 1999; Adamczyk et al., 2005; Wickens et al., 2005; Bailey & Iqbal, 2008).

2. *Post-interruption support*: Research that investigates providing assistance to recover from interruptions (e.g., St. John et al. 2005; Trafton et al., 2005; Scott et al., 2006; Wan et al., 2007).

In general, existing strategies to prevent interruptions or to find more opportune times to interrupt are not applicable to real-time and highly dynamic work settings like command and control because interruptions in these settings can provide valuable information that is directly related to the decisions at hand and hence cannot always be avoided (e.g. a phone call from a superior). Such strategies have motivated the recent development of software tools, called interruption recovery tools, to help mitigate the negative effects of interruptions in a variety of task environments (St. John et al. 2005; Trafton et al., 2005; Scott et al., 2006; Wan et al., 2007).

Unfortunately minimal attention has thus far been given to assisting personnel in time-critical, dynamic settings recover from interruptions. Time-critical tasks, such as command and control and emergency response, are particularly susceptible to the negative effects of interruptions. As the situational information dynamically changes in such tasks, distractions can result in important information being missed and incorrect decisions being made (Hughes, Randall, and Shapiro, 1992). Since life-critical decisions are often being made in these task environments, the outcome of an incorrect decision may be dire.

Even less research attention has been given to assist team supervisors in recovering from interruptions. Due to the collaborative and multitasking nature of time-critical command and control tasks (Cooke et al., 2006; Cooke et al., 2007), supervisors are more prone to frequent

interruptions (Jett & George, 2003) and, even though studies show that multitasking is not correlated to interruption handling abilities (Law et al., 2003), the sheer frequency of interruptions for team supervisors could play a major role in distracting them from important decision making tasks. Previous research has shown that frequent interruptions negatively affects task performance as well as a person's emotional state (e.g. increased frustration, annoyance and time pressure) and social attribution (e.g. less respectful of the task) (Adamczuck et al., 2004).

It is timely to address the problem of interruption recovery in time-critical supervisory-level tasks, especially in command and control centers, since supervisory-level personnel must deal with increasing amounts of advanced technologies, such as large screen displays meant to provide global situational awareness, showing real-time sensor data from around the world. The dynamic and highly collaborative nature of command and control environments, introduces particular challenges for the existing approaches to interruption recovery tool design, which often assumes that the task (e.g., a computer application) that a person will attempt to resume post-interruption will remain unchanged during the interruption. This assumption is not appropriate in dynamic task environments such as command and control. This research investigates visualization techniques that could be utilized to assist interruption recovery in such dynamic task environments.

1.2 Research Hypothesis

One of the main responsibilities of team supervisors (e.g. mission commanders) in command and control is overseeing the progress of a mission. This command role often involves using

computer displays that allow the commander to gain situational awareness of key events occurring in the operational environment and involving personnel under their command, that are highly dynamic in nature. An interruption recovery in this environment can result in the mission commander losing situational awareness and missing key events that may require a command response. Development of new design mechanisms, including interface design and information visualization techniques, may reduce such negative effects of interruptions. The hypothesis for this research is that, computational interruption recovery techniques can aid team supervisors in dynamic time-critical decision-making environments in recovering from interruptions effectively and efficiently.

1.3 Research Goals

Reducing the interruption recovery period has shown to be somewhat complicated for mission commanders overseeing UAV operators (Scott et al., 2005; Wan et al. 2007). In order to provide evidence for the abovementioned hypothesis this thesis investigates interruption recovery tools that address the challenges of the dynamic, time-critical, and collaborative task situation inherent to command and control operations. In particular, the goals of this research are to first investigate potential improvements to the design of software tools that help mitigate interruption recovery of team supervisors in mission control environments and second, to investigate the process of studying interruption recovery using user-based experimental methodology. In order to achieve its goals this research focuses on a representative time-critical supervisory-level command and control task. This task involves the supervision of a team of UAV operators in a command and control setting.

1.4 Thesis Overview

This thesis is organized into the following chapters:

- Chapter 1, *Introduction*, introduces the problem of interruption in time-critical decision-making environments and motivates interruption recovery technologies as a solution.
- Chapter 2, *Background*: discusses interruption research background and some of the related work that has been done in the past in the area of interruption recovery.
- Chapter 3, *Experimental Platform and IRA*: describes the developed experimental platform, representative task scenario and the interruption recovery assistant tool that was designed on top it.
- Chapter 4, *User Study 1, Baseline Study*: Presents the design and results of the first user study that was conducted to evaluate the effectiveness of the proposed interruption recovery tool on recovery time and decision accuracy of the mission commanders in a mission command and control scenario.
- Chapter 5, *The New Design of the IRA*: discusses the improvements to the interruption recovery tool and the experimental platform and presents the second user study that was conducted to evaluate the effectiveness of the improvements and the proper location for the IRA.

- Chapter 6, User Study 2: Evaluation of the IRA Location: discusses the statistical result of the second user study in addition to qualitative analysis of the data gathered using field notes and interview.
- Chapter 7, *Conclusions and Future Work*: describes the overall findings of this research and proposes potential areas of research to go together with the work done in this thesis.

Chapter 2

Background

Literature about interruptions falls into three main categories: (1) effects of interruptions; (2) preventative measures to minimize or control the occurrence of interruptions, and (3) assisting recovery from interruptions. The literature primarily focuses on the first category and, as discussed in Chapter 1, establishes that interruptions can have negative effects on individual and team task performance (e.g. Van Bergen, 1968; Kirmeyer, 1988; Cellier & Eyrolle, 1992; Czerwinski et al., 2000). In this chapter, I explore the research that has been done on the latter two categories, of both controlling the occurrence of interruptions and of assisting in recovery from interruptions. In the former area of research, McFarlane's seminal work (1998, 1999), which led to taxonomy for human interruptions in human computer interaction (HCI), set the stage for modern interruption recovery research, and is discussed first. The remainder of the chapter provides an overview of the taxonomy for human interruptions in HCI, followed by a discussion of subsequent work in the development of further techniques for preventing or timing the interruptions. Finally, I present existing computational tools for assisting in the recovery from interruptions.

2.1 McFarlane's Work on Human Interruptions

The topic of interruption recovery, especially in HCI, is a fairly new research area.

McFarlane's seminal research (1998, 1999), on the effects of interruptions in HCI, is based on the fact that the human brain is limited in making cognitive decisions and that this

limitation can cause critical errors in the presence of an interruption. McFarlane defined human interruption as “The process of coordinating abrupt change in people’s activities” (McFarlane, 1997, pg. 67) and proposed taxonomy of interruption (Table 1). McFarlane’s taxonomy provides a guideline for understanding different dimensions of human cognition in relation to interruptions and hence serves as the main theoretical tool to investigate an interruption as a complex process and to design user interfaces to mitigate the negative effects of interruptions. This research will focus on the Method of Coordination dimension of the taxonomy (Table 1, row 3) and more specifically on immediate interruptions, which address the situations where no explicit coordination of the interruption is provided.

Table 1. Taxonomy of Interruption (from McFarlane, 1997, pg. 73)

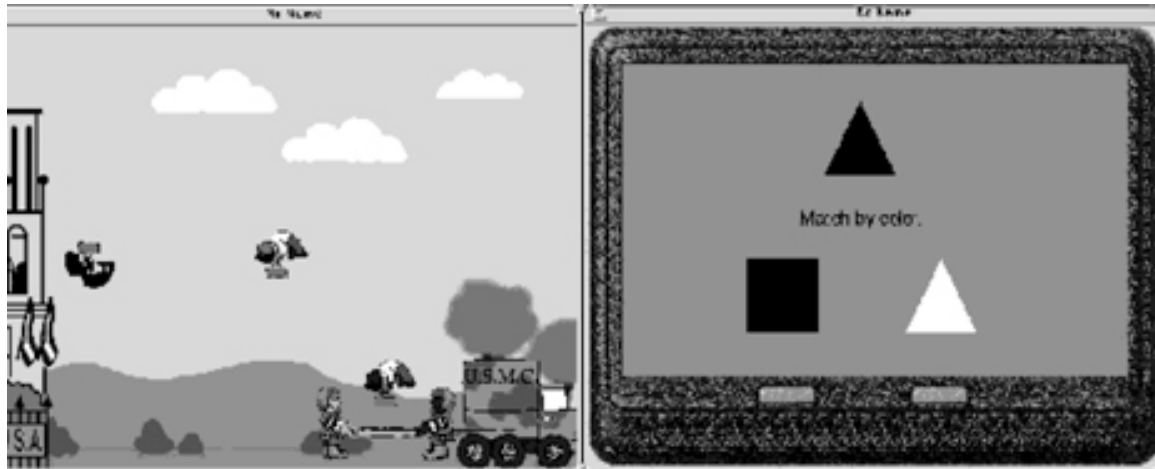
Descriptive Dimension of Interruption	Example Values
Source of Interruption	self [human]; another person; computer; other animate object; inanimate object. (See Table 12 on pg 132 for examples.)
Individual Characteristic of Person Receiving Interruption	state and limitations of personal resource (perceptual, cognitive, and motor processors; memories; focus of consciousness; and processing streams); sex; goals (personal, public, joint); state of satisfaction of face-wants; context relative to source of interruption (common ground, activity roles, willingness to be interrupted, and ability to be interrupted). (See Table 13 on pg 133 for examples.)
Method of Coordination	immediate interruption (no coordination); negotiated interruption; mediated interruption; scheduled interruption (by explicit agreement for a one-time interruption, or by convention for a recurring interruption event). (See Table 14 on pg 133 for examples.)
Meaning of Interruption	alert; stop; distribute attention; regulate dialogue (metadialogue); supervise agent; propose entry or exit of a joint activity; remind; communicate information (illocution); attack; no meaning (accident). (See Table 15 on pg 134 for examples.)
Method of Expression	physical expression (verbal, paralinguistic, kinesic); expression for effect on face-wants (politeness); signaling type (by purpose, availability, and effort); metalevel expressions to guide the process; adaptive expression of chains of basic operators; intermixed expression; expression to afford control. (See Table 16 on pg 136 for examples.)
Channel of Conveyance	face-to-face; other direct communication channel; mediated by a person; mediated by a machine; mediated by other animate object. (See Table 17 on pg 137 for examples.)
Human Activity Changed by Interruption	internal or external; conscious or subconscious; asynchronous parallelism; individual activities; joint activities (between various kinds of human and nonhuman participants); facilitation activities (language use, meta-activities, use of mediators). (See Table 18 on pg 138 for examples.)
Effect of Interruption	change in human activity (the worth of this change is relative to the person's goals); change in the salience of memories; change in awareness (metainformation) about activity; change in focus of attention; loss of willful control over activity; change in social relationships; transition between stages of a joint activity. (See Table 19 on pg 139 for examples.)

McFarlane (2002) highlighted the serious effects of interruptions in multitasking environments that are prone to frequent interruptions. He analyzes the effectiveness of the four methods of interruption coordination:

1. *Immediate interruption*, which is to interrupt with no prior notice. According to this method the interruption should be immediately handled regardless of state of the main task.
2. *Negotiated interruption*, in which there is usually a warning before the interruption happens and the interrupted person has some degree of control over the occurrence of the interruption.
3. *Mediated interruption*, which is an indirect interruption through a mediator such as a personal digital assistant (PDA) sometimes called a proxy.
4. *Scheduled interruption*, which is to interrupt in specified intervals like 10-minute cycles.

McFarlane (2002) conducted a laboratory-based experiment to compare these four methods to determine whether these methods have different effects on people's behavior during interruptions. In his experiment, participants were exposed to a computer-based dual task composed of a continual game task and an intermittent matching task. The game task involved catching characters jumping from a building using a stretcher that let them bounce three times before they landed safely. The purpose of the matching task was to interrupt the participant playing the game. In the matching task, the participant had to make a decision to choose one of the two shapes at the bottom of the screen and match it with a shape at the top corner of the display based on the rule on the centre of the screen, which was either to match by color or to match by shape (see Figure 1). The task was chosen because it was assumed to be almost impossible to automate and therefore needed at least a minimal focus of attention.

In his experiment, participants were interrupted according to the four different coordination methods discussed in above.



**Figure 1. McFarlane's main task (left, Taken from McFarlane (2002), Figure 3, Page 15)
Interruption Task (right, Taken from McFarlane (2002), Figure 5, Page 17)**

The empirical result of McFarlane's study (1999) revealed that interruptions significantly affect people's behavior. The result also revealed that the four coordination methods have different effects on task performance. In general, the negotiated approach caused the best overall performance, however the immediate approach showed a slight advantage over the negotiated approach when considering the timeliness of the interruption handling. For time-critical tasks like military command and control, this result indicates that, the immediate method of interruption coordination may work better.

2.2 Evolution of the Interruption Recovery

Researchers have subsequently used McFarlane's work to investigate the mitigation of the negative effects of interruptions. Researchers have taken the following two directions using McFarlane's research and methods of coordination:

- Finding a more opportune time to interrupt and how to interrupt (e.g. Altmann et al. 2003; Fogarty et al., 2005; Oulasvirta et al., 2006; Sen et al., 2006).
- Developing interruption recovery methods and technologies (e.g. Altmann and Trafton, 2004; St. John et al., 2005; Scott et al., 2006; Wan, 2007).

In the next sections, I provide a brief overview of the work that has been done in each area and how the topic of interruption recovery has evolved in recent years.

2.3 Controlling the Occurrence of Interruptions

Researchers have used McFarlane's negotiated-based interruption coordination method to develop interruption management systems. Latorella (1998) proposed a theoretical model of interruptions in complex systems. Interruption Management Stage Model (IMSM) is a model that looks at the interruption process which is based on human information-processing and cognitive abilities. According to IMSM there are four stages in the process of managing interruptions namely: detection of interruption, interpretation of interruption annunciation, integration of interruption into the main task, and the resumption of the ongoing task (McFarlane, 2003).

McFarlane (2004) also applied his negotiated-based interruption coordination method on the US navy ship's weapon system called Aegis using Human Alerting and Interruption Logistics (HAIL) mediation technology. HAIL is a decision-support system that delivers alerts based on cognitive abilities of the human user. McFarlane's work showed that such systems could increase the human capacity for processing critical alerts and improve the

situational awareness by changing the location of non-critical alerts to other display areas and by providing a negotiation-based on-demand access to information.

Bailey et al. (2005) expanded on McFarlane's negotiated solution and investigated the timing of interruptions. They found that interruptions occurring at the boundary between tasks and not during the task, helps mitigate an interruption's disruptive effects, including increased completion time, error rates, annoyance, and anxiety. Furthermore, Bailey et al. (2006) suggested a framework to analyze the task sequence and to specify the user's position in a task in order to determine a more opportune time to interrupt the user. According to Bailey's suggestion one should wait until the end of the task to interrupt. Monk et al. (2004) focused on cognitive distraction conditions in which attention is being switched back and forth between two tasks. For example doing an in-vehicle task such as checking the GPS interface can distract a driver. They also found that interruptions in the middle of the task had the most negative effect on drivers, and they suggested that in-vehicle systems be designed in such a way that non-critical alerts would interrupt the driver at the beginning or end of the subtasks such as changing lanes or merging with the highway traffic. However, the idea of interruption in the middle of tasks does not really apply to the supervisory tasks like military command and control tasks because the information in such work settings is dynamically changing and the task is normally ongoing and long.

Fogarty et al. (2005) also studied negotiation-based interruption handling and suggested a system that collects environmental cues using simple sensors (e.g. microphone) to assess the interruptability of the human user. The system looks for changes in behavior (e.g. talking)

or context (e.g. task or social engagement) and uses them as indicators to estimate the non-interruptability of the user.

Russell et al. (2005) studied email as a negotiable interruption and conducted interview of email users in different organizations to find that, interruption handling strategies in office environments differ depending on the situational parameters of both task or email (e.g. importance) and more specifically depend on the task goal. This could be best described as the user's will to direct his/her actions to achieve a task-related goal. These findings indicate that interruption recovery is very much dependent on the type of task and cognitive complexity of the work. Thus, in order to develop efficient interruption recovery mechanisms, researchers should avoid overgeneralization and should look more specifically in different work settings and grasp the cognitive and interruption process involved in those tasks.

Sen et al. (2006) at IBM developed a collaborative Bayesian filtering algorithm, which is a learning-based algorithm (e.g. amazon.com book recommendations,) to reduce interrupting alerts caused by collaborative tools, such as instant messaging or email, by filtering out unnecessary alerts. The algorithm was tested using a new technology called "FeedMe" which is an alert management system based on RSS¹ or ATOM² feed protocols.

Dabbish et al. (2004) investigated the effects of interruption on collaborative teamwork environments. Their empirical studies found that, awareness displays that show an appropriate amount of information about the attentional state of the interrupted person can

¹ Really Simple Syndication is a web feed technology.

² Atom Syndication Format is an XML language used for web feeds.

mitigate task disruption and improve the efficiency of the interrupted task. They also found that being a part of a team motivates the interrupter to use the awareness display to interrupt at a more opportune time, which helps to improve the performance of the interrupted.

2.4 Interruption Recovery

Most of the previous interruption recovery research in time-critical settings is based on the work of Trafton and Altman (2003) who conducted a task analysis of the interruption process and developed a model to describe this process. They expanded the McFarlane's negotiated method of interruption coordination and modeled the process of an interruption (Figure 2).

They focused on the time between when an interruption first becomes known (i.e. the interruption alert) and when the person begins to focus on the interruption (i.e. the secondary task). They called this period of time "interruption lag." Altman et al. (2003) then proposed that interruption lag could be used as a preparatory stage for interruption and empirically proved that this preparation can reduce the time it takes to resume their primary task (i.e. task "resumption lag"). The resumption lag is also known as reorientation time (Gillie and Broadbent, 1989) or interruption recovery time (Scott, Mercier et al. 2006). This concept is very important in that it simplifies the problem of interruption recovery in time-critical work settings to the problem of reducing the resumption lag in such tasks.

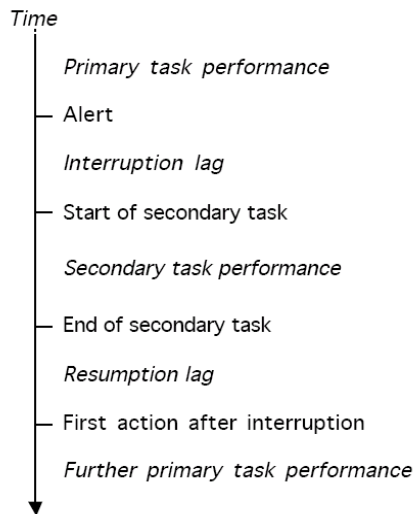


Figure 2. Interruption recovery process (Modified from Trafton et al., 2003)

Altman et al. (2003) also presented a simple cognitive process of interruption based on memory for goal theory (Altman and Trafton, 2002), which discusses how a goal is kept in different stages of memory. They argue that the main task retrieval after the resumption lag follows the goal-activation theory and is done either by prospective encoding of goal (e.g. mentally looking ahead) or retrospective rehearsal of the last task in working memory. Goal activation theory was one of the most important theoretical models adopted by researchers to better understand interruptions. Understanding the goal activation theory is important for interruption recovery since, according to Trafton (2005), the first step in recovery is to remember the last state before the interruption happened and goal activation theory essentially describes how task states are retrieved and kept in working memory in order to perform a task.

Oulasvirta et al. (2006) expanded on Altman and Trafton's model of goal-activation to retrieve data and called it "safeguarding." They use the theory of long-term working memory (Ericsson and Delaney, 1999; Ericsson and Kintsch, 1995, 2000; Ericsson and Lehmann, 1996) to better explain tasks with higher cognitive workload. Based on the theory of long-term working memory, task representations are being stored as large chunks of information in long-term memory through practice. Oulasvirta et al. also expanded on Altman et al.'s notion of encoding the goal. They argue that experts develop hierarchical knowledge representations called "retrieval structures" and use them to encode and retrieve the task after an interruption.

2.4.1 Change Blindness

An important phenomenon that should be considered in investigating interruption recovery, especially in dynamic environments, is change blindness. Change blindness happens when a person fails to detect some changes within a visual scene. Usually this happens when a visual disruption happens. Supervisory-level command and control tasks are complex monitoring tasks and hence are especially prone to change blindness since detecting mission changes is essential for gaining situational awareness. Previous research shows that interruptions, even for a short time (e.g. screen flickers), may cause the observer to fail to detect substantial changes in the scene or display (e.g. Simons, 2000; Rensink 2002; DiVita, bermayer et al. 2004). In HCI, it is well documented that looking away from the computer screen may cause change blindness (e.g. Rensink et al., 1997; Durlach, 2007). In time-critical command and control, most of the interruptions cause supervisors to get distracted from the main situational awareness, which in turn is the basis for the change blindness phenomenon.

2.4.2 Verbal and Visual Cues

One mitigation technique for the effects of change blindness is to use visual and auditory cues to assist in task resumption. Altman and Trafton (2004) found that existence of visual cues such as, a cursor or eyeball images where the user was last working as an interruption awareness tool in a user interface helps to reduce interruption recovery time. Trafton (2005) also found that subtle environmental cues largely facilitate the resumption of the task after an interruption. The use of verbal cues was studied as an alternative interruption recovery technique. Daniels et al. (2002) implemented an interruption recovery tool using a spoken dialogue interface to mitigate the negative effects of interrupting people while tracking military logistics requests from deployed ground troops. Using verbal queries, users could ask simple questions regarding the interrupted task such as their status before the interruption. While these techniques might be effective in static environments, in dynamic environments like command and control, there are often immediate situations that need to be taken care of after resuming the interrupted task, which makes this interruption recovery approach difficult to use effectively.

2.4.3 History Logs

Another to mitigate change blindness is to provide a text log of key events (e.g. Malin et al., 1991; St. John et al., 2005; Scott et al., 2006; Wan, 2007). Although providing a time-stamped log of key events can be an effective interruption recovery technique, in time-critical settings, like command and control, it can be time consuming to review the log of events after an interruption, thus the log itself can be a distraction from the main task. Therefore, having a log of key events by itself is insufficient for efficient and effective recovery. In

addition, information is not provided in the context of information elsewhere on the control displays. For example, geospatial information provided in textual form must be mentally translated into spatial form so that the person can relate the logged information to information that may be present on the current situation map.

Smallman & St. John (2003) integrated a text-based interruption recovery tool called CHEX (Change History Explicit), into naval air warfare situational awareness display called “Geoplot” (Figure 3). The intent of CHEX was to provide constant awareness of the important changes in a flight change detection task by dynamically populating a table with bookmarks of events in rows that could be sorted by the user for different tasking. Their study found that people using the dynamic table of events identified changes faster and more reliably than participants who were not provided with assistance.



Figure 3. CHEX history table (modified from Smallman & St. John, 2003)

2.4.4 Instant Replay

Another approach to mitigate the effects of change blindness, is to provide an “instant replay” feature that enables users to review the interrupted period usually with higher speed (St. John et al., 2005; Scott et al., 2006). St. John & Smallman (2005) argued that instant replays are familiarizing and may look realistic to users; but that this realism is naïve and these tools actually provide minimal benefit for identifying or detecting changes because of the effects of the change blindness. In this work, they reported a user study comparing an interface containing no change detection assistance with their CHEX system and two versions of an instant replay tool in a task scenario in which participants had to monitor the changes to the aircrafts in the Geoplot interface (see 2.4.3). They found that instant replay provided poor support for interruption recovery. Their research also showed that the textual event history table (CHEX) was effective in change awareness and overall interruption recovery. Scott et al. (2006) provided an alternative explanation for St. John & Smallman’s findings and claimed that; the inherent design limitations of the event replay tools might have influenced the results of their findings. For example, the event replay used in their study does not highlight any particular event. In other words, according to Scott et al., the way the event replay was used was problematic, not the event replay itself.

Scott et al. (2006) examined the impact of different instant replay techniques on interruption recovery in supervisory control of unmanned aerial vehicles (UAVs). Their study investigated an interruption recovery tool provided on a peripheral display in the primary task environment, called the Interruption Assistance Interface (IAI). As shown in Figure 4, IAI consisted of a replay window, an event timeline, and animation controls. The

information on the IAI is dynamically updated when an event happens (see Figure 4). They evaluated two versions of the IAI: a “discrete” replay version that allowed users to select an icon representing a historical event on an interactive timeline that caused the replay window to show the state of the main task display (a tactical map) at the time the event occurred; and a version of “animated” replay in which users could view an accelerated animated sequence of historical events within a desired time period. Their study found that the IAI’s replay tool, especially the “discrete” replay, was beneficial for interruption recovery, particularly when complex system changes had occurred during the interruption.

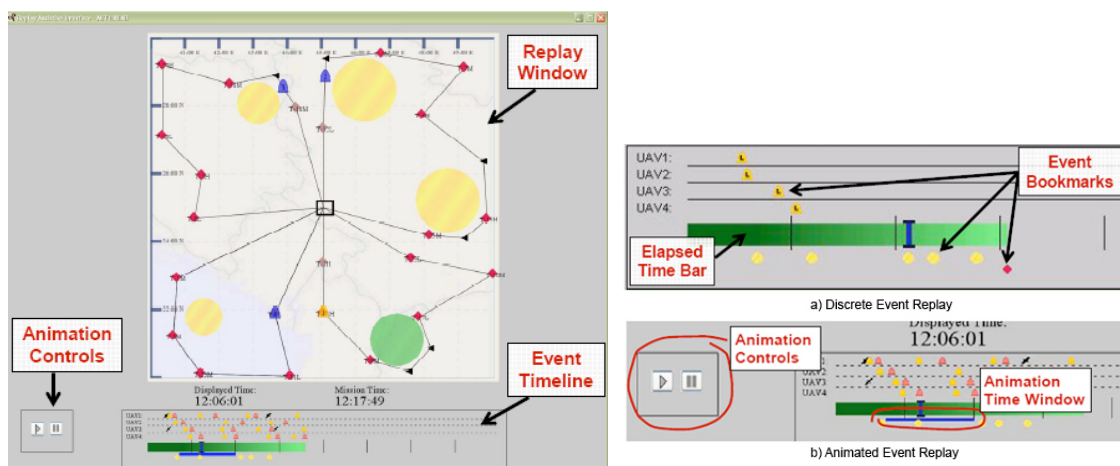


Figure 4. Interruption Assistant Interface (left) Discrete vs. Animated Event Replays (right)
(from Scott et al., 2006)

This research extends Scott et al.'s approach by focusing on providing discrete “replay” support to help supervisors in command and control tasks. The next chapter introduces the interruption recovery assistant (IRA) tool used in this research and the software testbed that was used to evaluate the interruption recovery assistance.

Chapter 3

Experimental Platform and IRA

Methodological evaluation of software tools aimed at helping supervisors in command and control centers is a challenging task. For example, gaining access to a live command and control environment is difficult, and testing experimental software is essentially impossible given the continuous nature of live operations. Therefore, laboratory-based testing of design concepts can provide a good first step to evaluate the effectiveness of supervisory-level assistance tools. In order to achieve this goal, it is crucial to have a rich experimental platform and challenging task scenarios complex enough to emulate such environments. With that goal in mind, a laboratory-based experimental platform was used to investigate interruption recovery and other collaborative technologies in a command and control setting. The remainder of the chapter provides an overview of the representative task scenario used in my investigations, followed by a discussion of a previous evaluation of an interruption recovery tool and its shortcomings. Next, the experimental testbed used in my investigations is discussed; along with modifications I implemented to improve this testbed for studying interruption recovery. Finally, an initial version of the interruption recovery assistant tool studied in my investigations is discussed.

3.1 Representative Task Scenario

In order to investigate supervisory-level interruption recovery techniques in an experimental setting, Scott et al.'s (2006) experimental platform was used, which incorporates a representative time-critical collaborative command and control task scenario. In this scenario, a team of unmanned aerial vehicle (UAV) operators is engaged in a ground force protection

mission in which the team performs intelligence, surveillance and reconnaissance (ISR) to ensure the safe passage of an important political convoy through a hostile region. Each operator is in charge of surveilling a separate area of interest (AOI) with multiple semi-autonomous UAVs, and detecting any threats to the convoy. It is assumed that these UAVs provide imagery only and do not have weapons capabilities to deal with any detected threats. The operator team can communicate with external intelligence sources to obtain extra surveillance information. The team must also coordinate with an external strike team to engage any detected threats also called targets.

As shown in Figure 5, the operations team involves three UAV operators each controlling three semi-autonomous UAVs and a mission commander who oversees the operator's progress and mission's overall progress. The human supervisor in this environment is the mission commander; responsible for making sure the convoy reaches its planned destination safely and as quickly as possible.

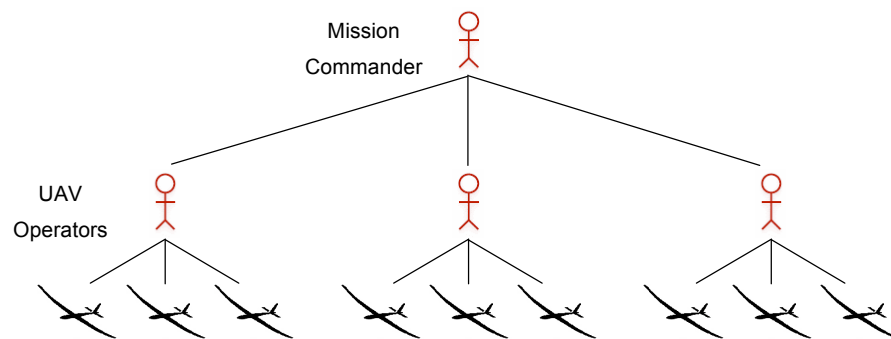


Figure 5. UAV team structure (from Scott et al., 2007)

3.2 Overview of the Experimental Platform

To realize the above-mentioned task scenario in a laboratory setting that facilitates the investigation of novel interface concepts to support collaboration and team performance, including interruption recovery, a mini command and control centre was previously developed at MIT's Humans and Automation Lab (HAL) (Scott et al., 2006). In this setting, the mission commander has access to three large screen interactive wall displays that provide situational awareness (SA) information of the mission task. The mission commander also has access to a command interface, provided to them on a tablet display, to implement time-critical decisions (Figure 6). All the interfaces in this platform work in real-time and are synchronized through a simulation engine located on a server outside the experimental room. The server interface is also used for scenario-creation and allows the experimenter to observe the mission progress from outside the experimental room.



Figure 6. Experimental Platform (from Top Left: Map Display, Mission Status Display, Remote Assistance display; Bottom left: Mission Commander Interface)

3.3 Supervisory-level Interruption Recovery in the Experimental Platform

Interruption recovery was previously investigated in the experimental platform environment by Wan (2007). In his study, Wan investigated an interruption recovery assistance (IRA) tool, similar to the IAI discrete event replay tool described in Section 2.4.4. IRA is described in more detail in Section 3.5. Wan (2007) evaluated the effects of IRA on the mission commander's recovery time, decision accuracy and overall task performance. The study involved two different user populations, one with military experience (e.g. ROTC³ students), and the other with no military experience. Although, Wan's study failed to show any statistically significant effects of IRA on these study variables, the results showed several interesting trends in the collected data. These trends indicated that IRA had negative effects

³ Undergraduate students enrolled in the US military's Reserve Officers' Training Corps program

on recovery time, yet had positive effects on decision accuracy especially when the mission commander was faced with a complex decision after the interruption. The study results also revealed a trend that IRA had more positive effects on participants with no military experience. Given these trends and the overall inconclusiveness of the study, Wan's research sets the stage for this research to investigate the issue further. More specifically, this research starts by addressing some of the observed limitations of Wan's study including:

1. *Mission environment may not be realistic enough.* The experimental platform environment should be rich and resemble a command and control environment in order to invoke more realistic decision-making. For example, there was fairly non-realistic behavior governing the targets (e.g. targets only attacked once even if the convoy was within their target range for a long time) in the simulation environment used by Wan, which can significantly impact participants' behavior during the experimental trials, and hence, may not provide the representative decision-making behavior for command and control tasks.
2. *Task scenarios may be too simplistic.* The complexity of the experimental task, especially the situations participants faced after an interruption has a significant influence on participants' behavior, their task performance, and their recovery time. An overly simplistic task may account for the lack of differences seen between assistance and no assistance conditions in Wan's study.
3. *Timing of interruptions may be too short.* Qualitative findings reported in Wan's (2007) study indicated that many participants relied on their memory to remember

task goals and the pre-interruption mission state. This indicates that the interruptions may not have been long enough for the situation to change enough to warrant needing assistance upon return from an interruption.

4. *Interruption tasks were not distracting enough.* Similar to the previous limitation, quantitative findings indicated that Wan's participants tended not to lose situation awareness of the mission states during the simple task they performed during the interruption. This indicates that the interruption tasks used by Wan, which consisted of tasks like mathematical puzzles, logical problems and reading comprehension, were not sufficiently distracting.

In order to address these limitations, modifications were made to both the experimental platform and the experimental methodology. The following sections describe the platform with the included changes while Chapter 4 describes a study that I conducted to re-evaluate the IRA tool in the redesigned platform with a modified experimental design.

3.4 Redesigned Experimental Platform

In order to address the first two limitations discussed above, related to experimental environment being non-realistic and the task scenarios being too simplistic, recommendations that were made by Scott et al. (2007) were implemented in the platform environment. In particular the non-realistic behavior governing the targets in the simulation environment needed major improvements. The following sections describe the redesigned experimental platform and mission task.

3.4.1 Ground Force Protection Mission

The experimental platform allows a participant to play the role of the mission commander in the task scenario described in Section 3.1 using three large screen displays and a tablet PC. If needed the commander can perform time-critical decisions such as holding or releasing the convoy, rerouting the UAVs, and requesting external intelligence using an interface provided to them on a portable display. An additional command option, “change convoy route”, was implemented to address Wan’s limitations and to increase the complexity of the mission environment. The next section provides more details about these experimental interfaces.

The platform also includes a measure of convoy’s health status. At the beginning of each scenario convoy’s health is 100% and as incidents happens during the mission, convoy’s health decreases. The convoy health decreases whenever the convoy is being attacked and while it is still in the target range of an attacking threat. The convoy also loses health when it is being held in its current location. This measure is provided to help motivate the participants to keep the convoy safe and encourage them to move the convoy as fast as possible.

3.4.2 Large-screen Wall Displays

3.4.2.1 Map Display

The map display (MD) is a situational awareness interface provided on a large screen display. It provides a geospatial map of the mission, including the assets (e.g., convoy, UAVs) and hostile (e.g. targets). The map dynamically changes to enhance the mission commander’s awareness of mission events and operators’ surveillance progress. As shown in Figure 7, the map display is divided into three main sections: view filters which enable

mission commander to change the level of detail being displayed on the interface, map of AOIs, and threat summary and strike schedule timeline which will be described in more detail.

The map section of the interface is divided into three main areas, each of which presents the areas each operator is responsible for, also known as “area of interest” (AOI). The surveillance progress of each operator can be observed easily by comparing the areas with black transparent overlay (i.e. not surveilled yet) and areas which are clear (i.e. UAVs have surveilled the area). Ideally clear areas should change to black overlay as time progresses (Bisantz et al., 2006), however this feature is not implemented in this version of the testbed.

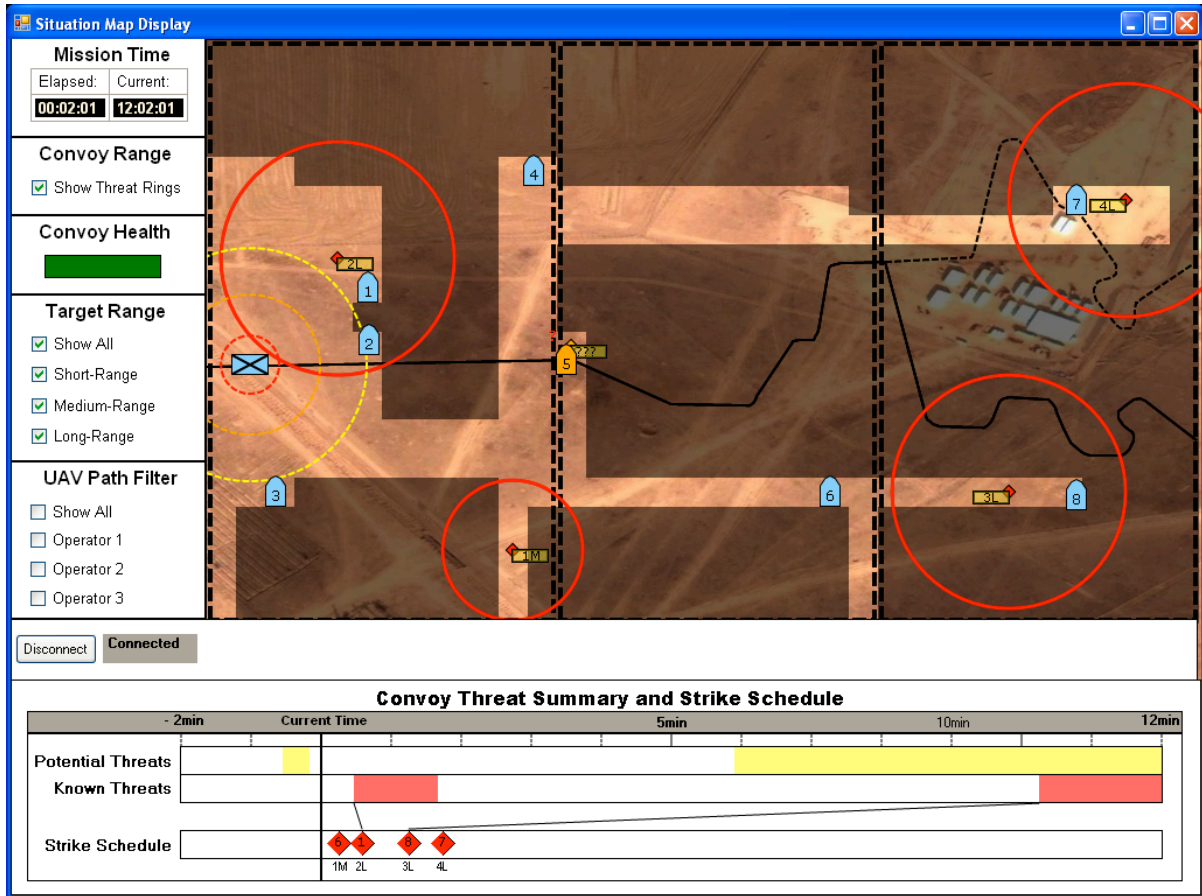













Figure 7. Map Display

Table 2 shows the symbology used in the experimental displays, which is based on military standard MIL-STD 2525B (DOD, 1999) and was changed to conform to the requirements gathered through a previously conducted cognitive task analysis (CTA) (Scott et al., 2006; Scott et al., 2007). For example, different colors are used to clarify the UAVs' and targets' status. Based on this methodology, whenever an operator receives imagery from a UAV (e.g. UAV finds a potential threat), the UAV changes color to orange and a red target

(i.e. known threat) icon appears on the map at the discovered location. When the operator is done with the identification task, the UAV changes color to blue and continues surveilling.

Table 2. Map Symbology used throughout the team displays (from Scott et al., 2007).

Map Entity	Symbology
Convoy	
Convoy route	
UAV	 (nominal)  (reviewing ATR imagery)  (down)
Targets	 (identified)  (potential target detected)  (destroyed)
AOI boundary	 (nominal)  (request for assistance received from operator)  (OPL critically low)

ATR = automatic target recognition
 WR = weapons range
 OPL = operator performance level

The threat summary and strike schedule timeline are located at the bottom of the map display (Figure 8), and provides up-to-date information regarding the time and duration in which the convoy is or will be within the attack range of potential or known target(s) using colored boxes also known as “threat envelopes.” The yellow threat envelopes represent potential threats and red threat envelopes represent known threats. The timeline also provides an up-to-date strike schedule, which provides the time in which targets were or are expected to be destroyed by the external strike team.

An important information visualization technique used in the timeline is the line connecting the targets in strike schedule to the beginning of their associated threat envelope.

Previous research shows that humans are good in perceiving differences in angles (Ware, 2000); hence, the connector line creates an emergent feature that warns mission commander of a situation called a “late strike.” These are strikes that happen after the convoy is within the weapon’s range of the target. For example a connector line skewing to the right means that the convoy is approaching a known threat but the threat will be destroyed before the convoy will be within its weapon’s range (e.g. target 4 in Figure 8).

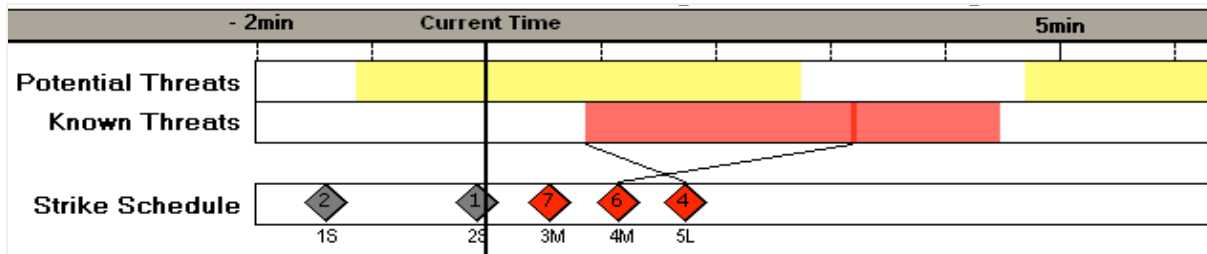


Figure 8. Strike Schedule and Potential Threat Timeline

3.4.2.2 Mission Status Display

The mission status display (MSD) display provides an overview of the current and expected operators’ performance as well as several other mission status updates (Figure 9). In particular, MSD contains four main components: operator performance summary, operator activity overview, communication link diagram and communication link status.

Operator performance summary is a graph that reflects the current and expected ISR performance of each operator. Each point on the diagram corresponds with a 30 seconds period. For the visualization of future performance, a trend for performance gets calculated.

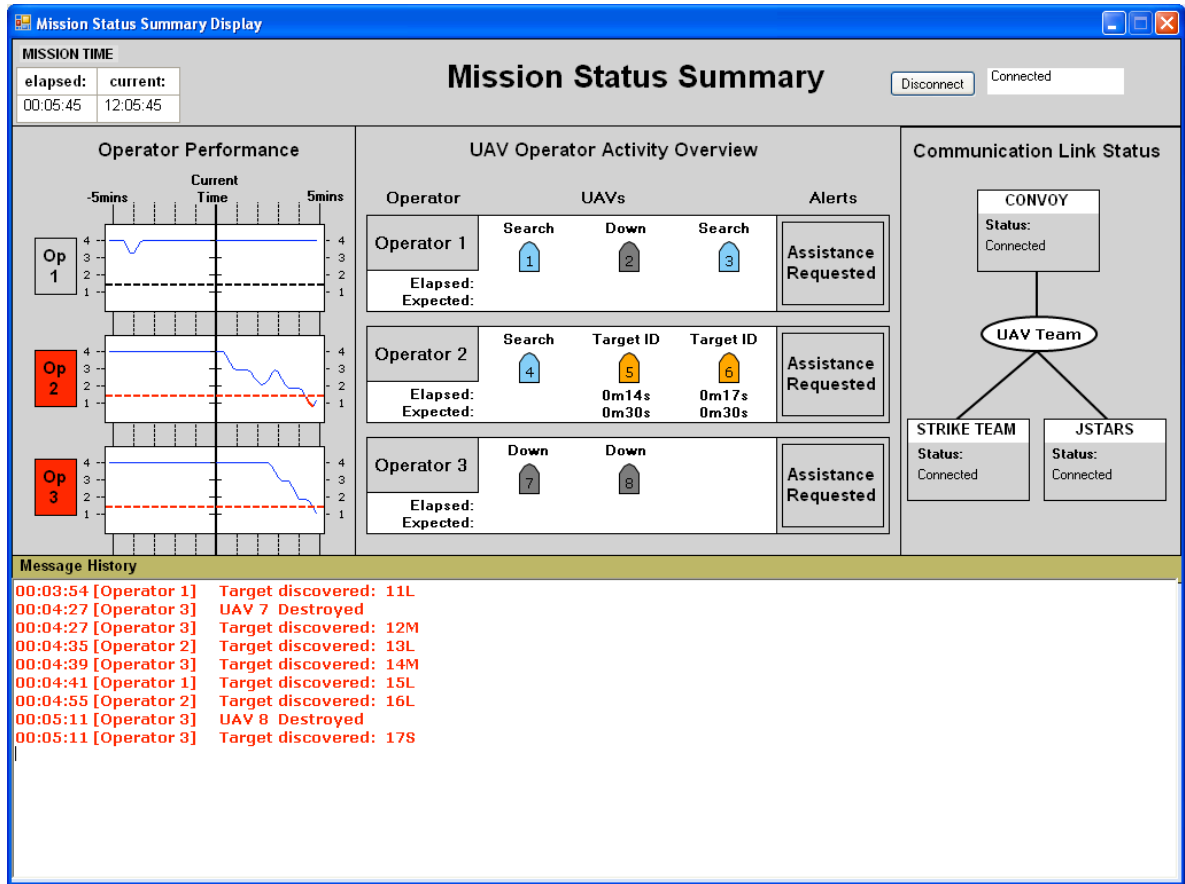


Figure 9. Mission Status Display

If the operators put the convoy's safety in jeopardy through poor ISR performance, a red alert would trigger beside their performance diagram. The performance ranking is based on a 4-point scale with 4 being excellent performance and 1 being critically low performance.

UAV operator activity diagram provides a visual summary of the tasking for each operator's assigned UAVs. This diagram displays the same symbology and coloring as the MD to show the UAVs' status. In addition, in order to better assist the mission commander in assessing the operators' performance, the timing information for identification task is given below each UAV icon. For example when a UAV finds a target, not only does its symbol

turn orange in MD and MSD, but also the time-on-task and the expected identification time is shown in the operator activity diagram. This information can help the supervisor to more accurately decide if the operator needs assistance with the identification task. It is also possible in the experimental platform to simulate an assistance request from an operator which triggers an orange “assistance request” alert.

Communication link status provides an up-to-date overview of the connection status between the UAV team and the convoy, as well as the external sources such as the strike team. If the UAV team loses communication with either the convoy or the external sources, the icon associated with the disconnected sources, as well as their connecting lines, change to red dotted line and when the communication is reconnected, the lines change back to their nominal solid black. There is also a message inside each icon, which states if the communication link to that source is “connected” or “disconnected.”

Finally, the *message history log* provides a time-stamped history of all the messages sent from external resources, UAV team and the convoy to mission commander as well as critical system messages. As discussed in Chapter 2, this message history log acts as a basic interruption recovery technique that can be used in situations when the convoy is not under imminent danger.

3.4.2.3 Remote Assistance Display

The remote assistance display (RAD) allows the mission commander to help (simulated) remote operators who have difficulties identifying targets. As shown in Figure 10, it contains four main components:

- *Assistance requests history* provides a log of current and completed assistance requests with the most current request on top. This includes the following information to assist the mission commander overseeing the request history: operator number, UAV number, expected identification time, and target type.
- *Assistance request communications* is a time-stamped history log of all the communication between remote operators and the mission commander in regards to assistance requests.
- *UAV tasking* provides an up-to-date UAV status filtered by operators using three tabs. This is similar to the UAV operator tasking activity overview and helps the mission commander to observe the identification times and, if needed, to help the UAV operators. In addition, if an operator requests assistance or the mission commander requests status updates from an operator, this section displays the automatic target recognition (ATR) imagery sent from the corresponding UAV so that the mission commander can help the operator with the target identification task.
- *Operator assistance* enables the mission commander to request status updates from UAV operators and to clarify and confirm the target classification and its strike priority. The mission commander can change these values and send clarification back to the operators. For example in Figure 10, the mission commander requested a status update from operator 2 for UAV 5.

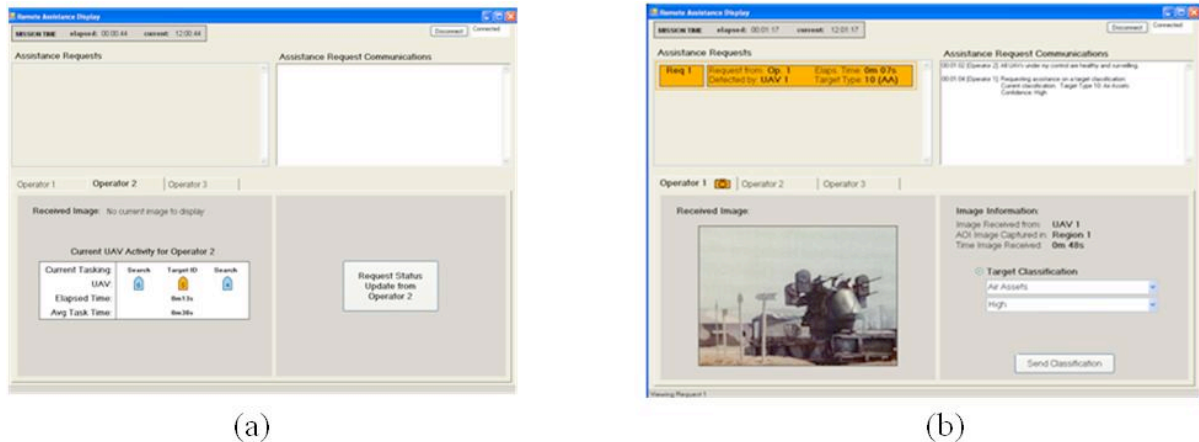


Figure 10. Remote Assistance Display: (a) in nominal monitoring state, (b) once an operator assistance request has been received.

3.4.3 Mobile Device

3.4.3.1 Mission Commander Display

The mission commander display (MCD) is an interactive interface provided on a portable tablet display, which has two main components (Figure 11):

- Interruption Recovery Assistance (IRA) tool: An interactive timeline of important events. IRA will be discussed in more detail in the next section.
- Mission command functions: Features that enable the mission commander to command decisions during the mission.

The mission commander can make four types of decisions using the MCD in order to protect the convoy:

- *Hold/Release the convoy.* Using this command, the mission commander can control the convoy movement and hold it in case of an imminent threat. The convoy will lose health while it is being held.
- *Reroute UAVs* to take over the uncompleted surveillance route of a destroyed UAV. Using this command, the mission commander can reassign an active UAV from the active UAV list to a destroyed UAV from the inactive UAV list.
- *Change convoy route* to the alternate back-up route, in case the main route is unsafe for passage. As discussed above, this is a new command implemented to address Wan's study limitation.
- *Ask for external intelligence from Joint surveillance & target attack radar system (JSTARS),* which is an aircraft capable of long-range surveillance. In the current simulation, using JSTARS clears two minutes ahead on the convoy route, but it can only be used three times during the mission. A new text-box beside the request button was also added to provide the remaining number of available JSTARS requests.

In addition, in order to help the strike team, the mission commander can report late strikes, which are strikes that are currently scheduled to happen after the convoy enters the danger area of known threats.

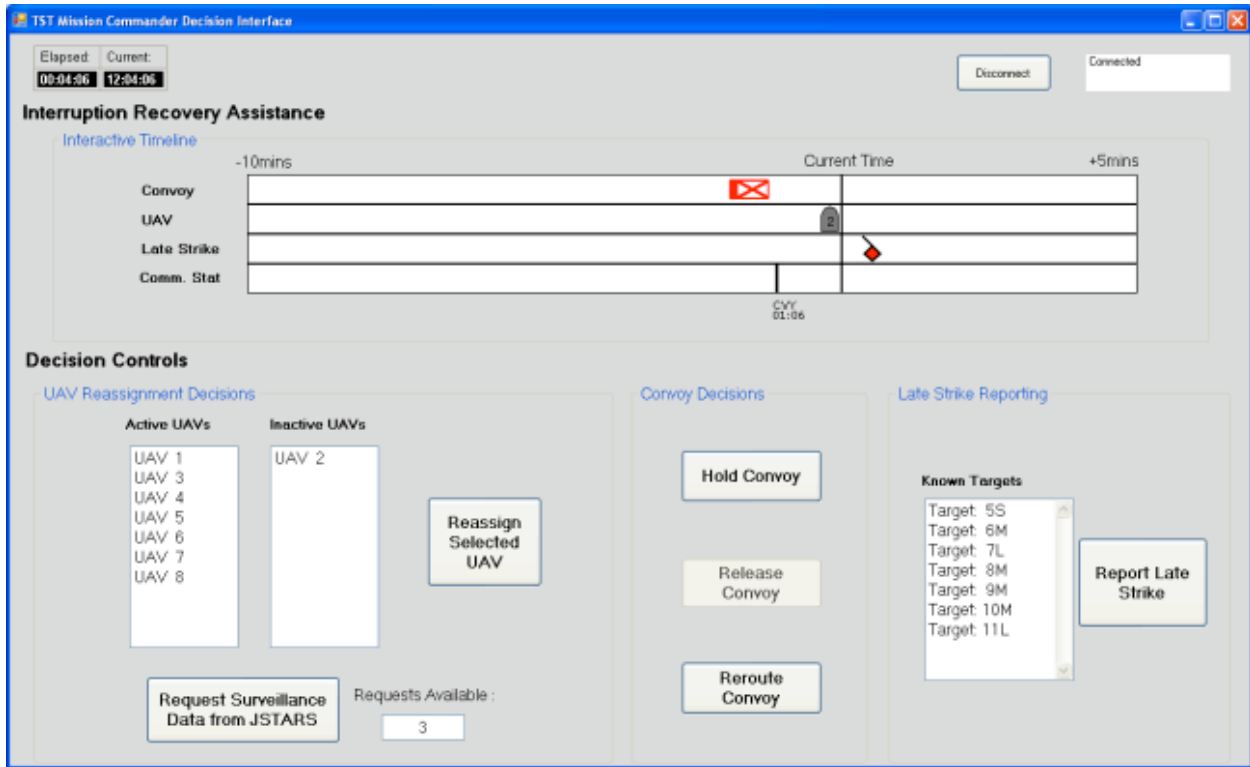


Figure 11. Mission Commander Display

3.5 Interruption Recovery Assistance (IRA) Tool

The IRA tool is an interactive timeline that provides a 10-minutes history and 5-minutes prediction of important events directly related to the mission commander’s decision-at-hand.

As shown in Figure 12, IRA has four rows, each of which contains iconic bookmarks representing a historic or imminent critical mission event.

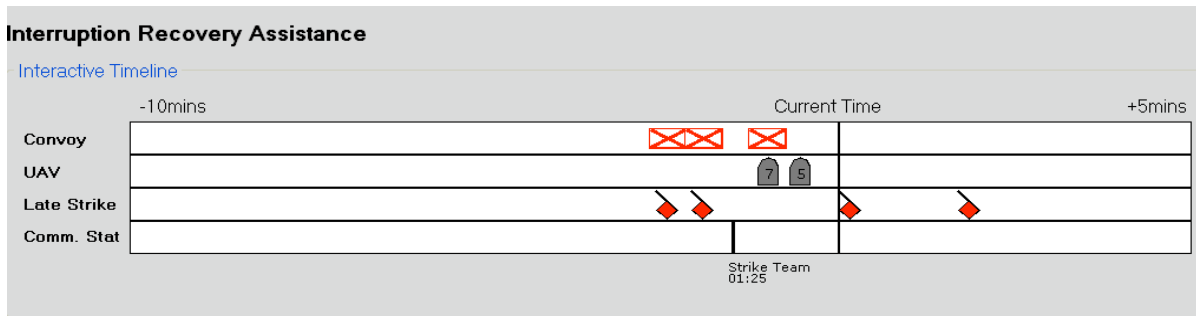


Figure 12. Interruption Recovery Assistant (IRA) Tool

Table 3 describes the four events that are monitored by the IRA tool, namely, the convoy attacked, UAV destroyed, late strikes, and communication status changed events. It also describes what mission event triggers the addition of the associated event bookmark to the IRA timeline. The icons in the first three rows of IRA are selectable by the user and interacting with them causes more information to be displayed on the map display, in other words, it triggers an “event replay” action. For example, if the mission commander selects the convoy-attacked icon, the exact location of where the convoy was attacked is shown on the map display. Table 3, describes the specific replay action for each re-playable event.

Table 3. Event bookmarks (from Scott et al., 2006)

Icon	Event	Triggered By:	Select action/Bookmark description
	Convoy Attacked	Convoy gets attacked	Draw a red X on the spatial map (Map Display) where convoy was hit.
	UAV Destroyed	UAV is destroyed	Draw a red X over the destroyed UAV on the spatial map.
	Late Strike	A newly scheduled target strike that will not eliminate the target before the convoy passes within its weapons range.	Draw a box around the corresponding target on the strike schedule.
 CVY 00:30 J* 01:40	Communication Status Changed	If any of the communication (JSTAR, Convoy, Strike Team) links changes status (connect/disconnect).	Display red dotted line on IRA timeline if communication was disconnected, show black solid line if communication was reconnected. The text under the line reveals more information about the type of communication (J* for JSTARS, Strike Schedule and CVY for Convoy) and the time it happened in the past (i.e. 00:30 means in happened 30 seconds ago)

As discussed in this chapter, the IRA tool showed a positive trend in recovering mission commanders from interruptions; however, an important design issue of the IRA tool that is being addressed in this research is that using the tool which is located on a peripheral display, causes distraction from the main task. The proposed changes to the design of the IRA tool will be discussed in Chapter 5, but before implementing these changes, a baseline study was conducted first to evaluate the platform changes and to re-evaluate the current IRA design in this new platform.

Chapter 4

User Study 1: Baseline Study

This chapter outlines the user study conducted in order to further investigate the utility of the IRA tool on recovery time and decision accuracy of team supervisors in a simulated UAV control task. First, I describe the evaluation methodology used, and discuss the modifications made to the task scenarios and the interruption task to address the limitations observed in Wan's (2007) study. Next, the results of the user study will be discussed in detail.

4.1 User Study Hypotheses

As discussed in Chapter 2, a goal of interruption recovery is to reduce the resumption lag, or interruption recovery time, after the interruption. That is to reduce the time between the interruption's end and resumption of the primary tasks. IRA provides a concise visual summary of important events happening now and which happened in the past. This visual summary enables the mission commander to get back up to speed on the current mission status as quickly as possible.

Hypothesis 1: IRA helps minimize the interruption recovery time of the mission commander after an interruption.

One the most important negative effects of interruptions is increased error rates or mistakes (Van Bergen, 1968; Kirmeyer, 1988; Cellier & Eyrolle, 1992; Czerwinski et al., 2000). As discussed in Chapter 1, in supervisory-level command and control, mistakes may be very costly due to the life-critical nature of these tasks. Thus, an important goal of an interruption recovery tool is to improve decision accuracy, or the correctness of decisions made following

an interruption. IRA provides interactive event bookmarks of important events that allow the mission commander to better assess the situation and to make an informed decision after an interruption.

Hypothesis 2: IRA helps the mission commander to make more accurate decisions, especially in complex situations.

4.2 Experimental Tasks

Participants were asked to play the role of the mission commander in the ground force protection mission task described in Section 3.4.1. This task served as the “primary task” in the experiment. In order to address the third and fourth limitations of Wan’s study (see Section 3.3), a new secondary task was developed. This task was designed to be more engaging (thus more distracting), as well as to be longer.

In this task, participants were asked to find a certain location on the world map using provided hints (Figure 13). The *PlaceSpotting* application was used. *Placespotting* is an open-source online application based on the Google map platform (www.placespotting.com). Five military-related search tasks were developed in order to create a more realistic command and control environment (see Appendix H). Participants performed this task for two minutes. This interruption was longer than the interruption task used in Wan’s study, which was only one minute, to minimize the opportunity for participants to rely on their memory of the mission situation before the interruption.

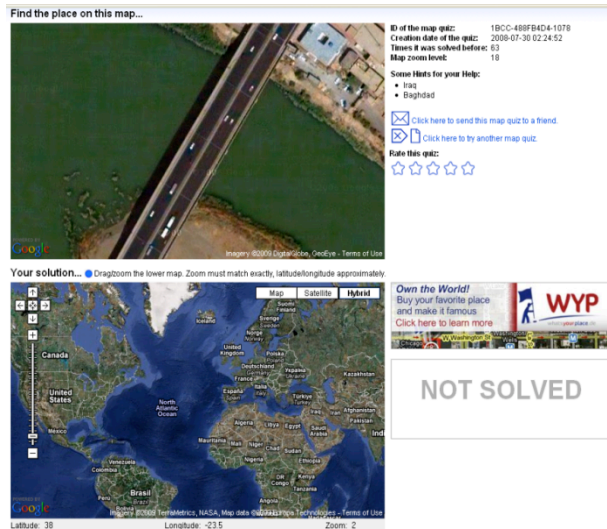


Figure 13. The interruption task

The secondary task scenarios were carefully designed to be engaging and fun. However, there was still no guarantee that the task would completely take the participants' mind off the mission. In order to further ensure distraction, the experimenter talked to the participants during the tasks and gave them several hints. In addition, in order to motivate the participants to be more engaged in the task, they were told that their performance in the secondary task would be counted toward their overall performance calculation to win the prize for best performance (described below).

4.3 Participants

Twenty-four computer-literate participants (18 male, 6 female), ranging from 18 to 58 years old, were recruited from the MIT community. Twelve participants were students with previous military training who were either enrolled in Reserve Officers' Training Corps (ROTC) program at MIT or had graduated from military academies like the Air Force

Academy. Of the twelve remaining participants, nine were either undergraduate or graduate students at MIT and three were engaged in research at MIT. Participants received \$30 remuneration and they were told that the best performer would receive \$100.

4.4 Apparatus

The experiment was conducted using the experimental platform described in Chapter 3. The map mission status, and remote assistance displays were provided on three 42-inches (1024x768 pixels), wall-mounted Smartboard interactive plasma displays (Figure 14). A 12.1-inch, Wacom *Cintiq* tablet display, used to show the Mission Commander Display, was located on a wooden podium positioned near the large displays. The experimental interfaces were developed using the Microsoft *C#.NET* programming language. A Dell *Optiplex GX500* server computer outside the experimental room was used to simulate the task environment.

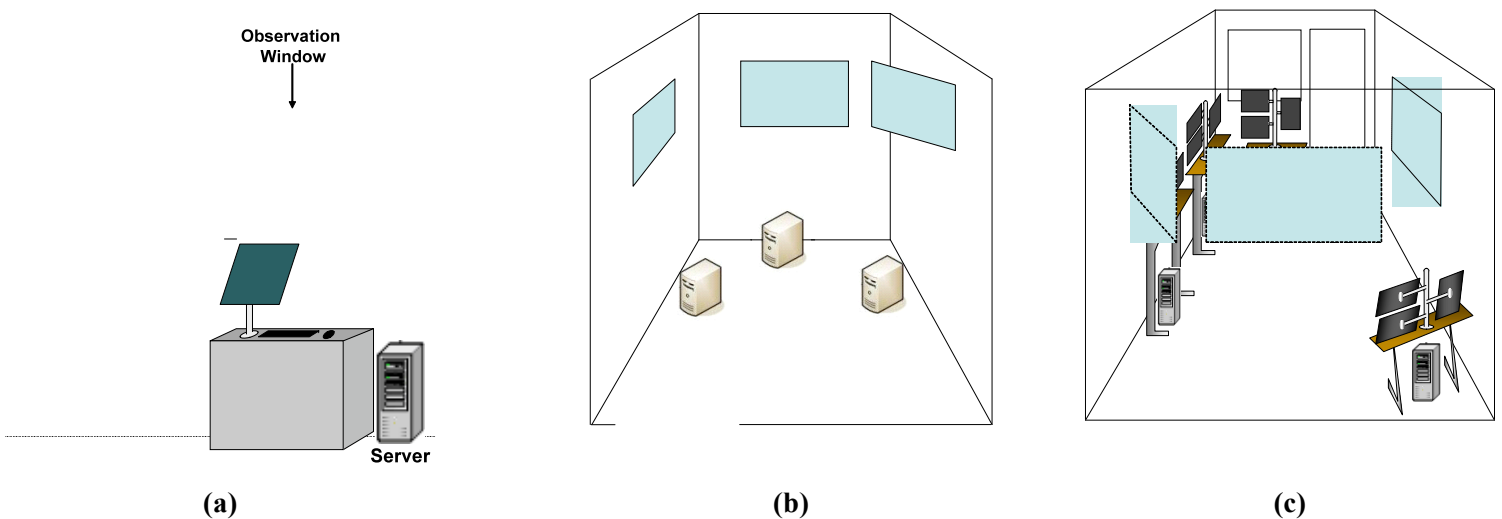


Figure 14. Command center laboratory equipment: (a) collaboration server, (b) three large-screen wall displays (c) three operator workstations (from Scott et al., 2007)

4.5 Design

A 2 (assistance type) x 2 (decision difficulty) experimental design was used, with repeated measures on both the assistance type and decision difficulty factors. The two assistance types were: assistance and no assistance. In the assistance condition, participants were provided the IRA tool. In the no assistance condition, participants performed the experimental task without the IRA tool. The two decision difficulty conditions were: simple and complex. In the simple condition, there was only one possible decision that could address the mission situation facing the mission commander following an interruption. In the complex condition, several decisions could be made to address the situation; however, only one decision was optimal and properly fulfilled the mission objectives.

Two main dependent variables were used: interruption recovery time and decision accuracy as discussed in Section 4.1. Decision accuracy was measured using a nominal score that was assigned to the action taken after each interruption, as follows: 0 = no action taken (after 50 seconds); 1 = Suboptimal decision; 2 = Optimal decision. The simulation server records each decision in a time-stamped log along with other important events.

4.6 Procedure

Participants started by completing an informed consent form (see Appendix A) and a background questionnaire (see Appendix B) that gathered their demographic information. Next, they completed a computer-based PowerPoint tutorial that outlined the experimental tasks and explained the software interfaces (see Appendix E). Participants in both assistance conditions were shown the same tutorial including several slides explaining IRA. The participants then completed two practice sessions in the experimental task environment. The

first practice session was an active training in which participants were asked to observe changes of a partial scenario (see Appendix D). Using a carefully designed scenario, important functionalities of the interfaces were explained and the participant was asked questions to check their comprehension (detailed in Appendix F). This session took approximately 15 minutes.

The second practice session was a complete task scenario in which the participant had to perform the task without the experimenter's aid. In this session, the participant was interrupted once to complete the secondary task. The purpose of this training was to expose the participants to all the penalties involved in the mission and to familiarize them with subtle functionalities of the system. This training gave them hands-on practice performing a moderately hard task scenario and took approximately 20 minutes.

In order to ensure that a sufficient level of task competency was reached, a standardized benchmark test was added to the experimental design. The benchmark test was integrated into the simulation server interface located on the server outside the experimental room. The interface shows the detailed measurements of specific task performances such as, the number of targets found or the number of operator status updates requested. Using this interface, the experimenter can observe the participants' task performance and check if it meets the minimum requirements in order to advance to the experimental trials. If the benchmark test showed below minimum requirements performance, the participant's results were discussed and more training was provided.

The participant then completed two full task scenarios as the experimental trials. These scenarios included two interruptions each, and took 20 to 25 minutes to complete. Before commencing the second trial, participants were asked to review a mini-tutorial explaining the IRA tool for those who saw the no assistance condition first, and the Mission Commander Display without the IRA timeline for those who saw the assistance condition first. There was a 5-minute break after the second trial. After the break, participants took part in a post-experiment interview in order to gather feedback about the interfaces and the task scenario (see Appendix G). During the interview, the experimenter walked them through the post-interruption situations in both trials and the decisions they made using a video captured by the Camtasia⁴ software for real-time recording. Both trials and the interview were videotaped for further analysis. The entire experiment lasted approximately 150 minutes.

4.7 Results

Both quantitative and qualitative analyses were performed to evaluate the effectiveness of the IRA tool on recovery time and decision accuracy. The following sections summarize the results of these analyses.

4.7.1 Quantitative Results

With regards to interruption recovery time, a 2 x 2 repeated measures analysis of variance (ANOVA) comparing assistance type and decision difficulty, blocking for military experience, showed significant differences between assistance type levels ($F(1,22) = 64.43, p < .0001$). The ANOVA found that on average people recovered faster with assistance ($M = 9.77s, SD = 3.58s$) compared to no assistance ($M = 28.04s, SD = 12.09s$). No significant

⁴ A screen video capture program for Microsoft Windows (Wikipedia.org)

difference was found between decision difficulty levels ($F(1,22) = 1.50, p = .234$), for the interaction between assistance type and decision difficulty levels ($F(1,22) = 0.14, p = .709$). The result also showed no significant difference for interaction between assistance type and experience ($F(1,22) = 0.06, p = 0.804$) or interaction between decision type and experience ($F(1,22) = 2.05, p = 0.167$). As shown in Figure 15, the blocking for military experience was used because based on earlier investigations differences were seen between these populations. On average, recovery time for non-military participants and military participants were comparable (non-military: $M=19.06s, SD=12s$; military: $M=18.75s, SD=15.62s$). The improved training, including the benchmark testing may have helped participants with no military experience become comparable to their military counterparts in this task.

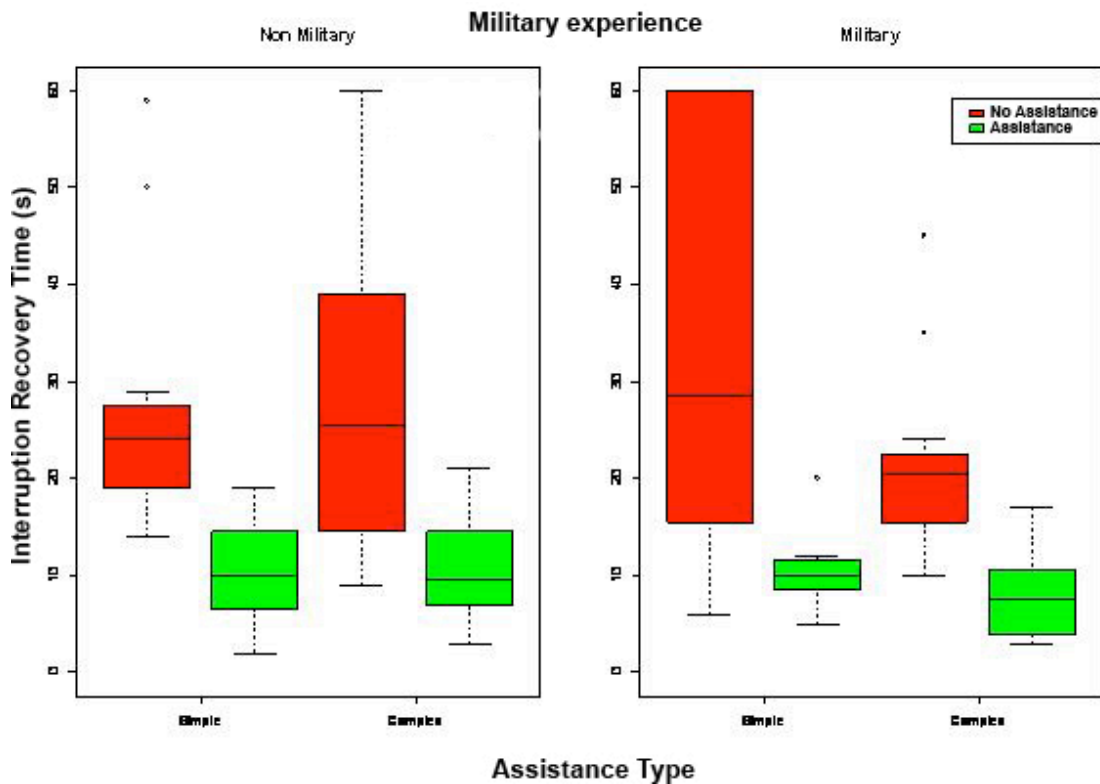


Figure 15. Interruption recovery time between assistance conditions

In general, participants who started with the no-assistance condition in their first trial improved their recovery time 20.3% using IRA in their second trial (31.21s to 24.88s) and participants who started with the assistance condition improved slightly in their second trial (10.17s to 9.38s). This result shows that participants improved their recovery time in their second trial in both assistance types but people who had IRA in their second trial improved their recovery time considerably more (i.e. around 65%). This suggests that there may have been some learning effects. In order to investigate the possible learning effects, the data were analyzed with the order of the trials as an input in the repeated measures ANOVA. This test showed no significant order effect (see Appendix J for more details on this analysis).

With respect to decision accuracy, the effect of IRA on simple decisions and complex decisions were tested separately. Due to the small sample size and the binary nature of results for decision accuracy, a non-parametric statistical test was used. McNemar's test with the continuity correction showed significant difference between decision accuracy for simple decisions across assistance types (Chi squared = 4.167, $p = .04$). A significant difference was also found for complex decision accuracy across assistance types (Chi squared = 5.786, $p = .02$). In both cases IRA improved decision accuracy. These results demonstrate the effectiveness of the interruption recovery assistance in improving decision accuracy.

4.8 Qualitative Results

A video analysis was performed on the post-experimental interview and the observation notes were reviewed for important events. These analyses revealed more information about the utility of the interruption recovery tool and the participants' behavior. As mentioned above, we designed challenging scenarios to promote the perceived utility of the interruption recovery tool. In fact, most of the participants found the mission task challenging. All 24 participants took advantage of the assistance. In addition, only 12 participants claimed to use the tool only after the interruptions. This reveals the fact that participants not only used the interruption recovery assistance tool for interruption recovery but also used it to gather situational awareness during the mission.

The findings also provide evidence for the effectiveness of the secondary task in creating a more realistic interruption as most of the participants (19 people) found the interruption task distracting enough to take their mind off the mission. Several factors may explain this behavior: First, the interruption task was a stimulating task to perform for most of the

participants and distracted them from the main task. Second, the task was related to the main task and was more realistic since mission commanders' job in command and control may involve frequent map search activities. Finally, participants were told that their performance would be considered in their overall performance rating which encouraged them to focus on the secondary task and hence stopped them from thinking about possible post-interruption situations in the main task.

Participants in Wan's study reported the use of their memory of the situation before the interruption occurred as their main strategy to recover from the interruptions. Changing the length of the interruption from 1 minute to 2 minutes helped in preventing the participants from memorizing the situation. In practice, interruptions may be long and humans are susceptible to memory loss over time.

4.9 Discussion

The results of this user study validated my initial study hypotheses: a significant decrease in recovery time was founded for mission commanders using IRA and a significant increase was found in mission commander's decision accuracy with the presence of IRA. In general the result indicated the importance of having a more realistic environment when studying complex tasks. As hypothesized, the perceived utility of the IRA tool was increased by making the scenarios more challenging and by creating a more realistic experimental platform. Since supervisory-level command and control tasks in real life are typically cognitively challenging, any simulation of these tasks or the systems involved should enforce a comparable cognitive demand. The current result informed the design of the new IRA tool in the experimental platform environment.

Even though these results indicate the potential positive effects of the IRA tool on mission commander's interruption recovery, having IRA on a separate display is in itself a distraction from the main task. In order to determine whether it is possible to improve the effectiveness of an interruption recovery tool, the following chapter describes an alternative design possibility for the IRA tool, involving the integration of the event timeline directly into the main task displays.

Chapter 5

The New Design of the IRA

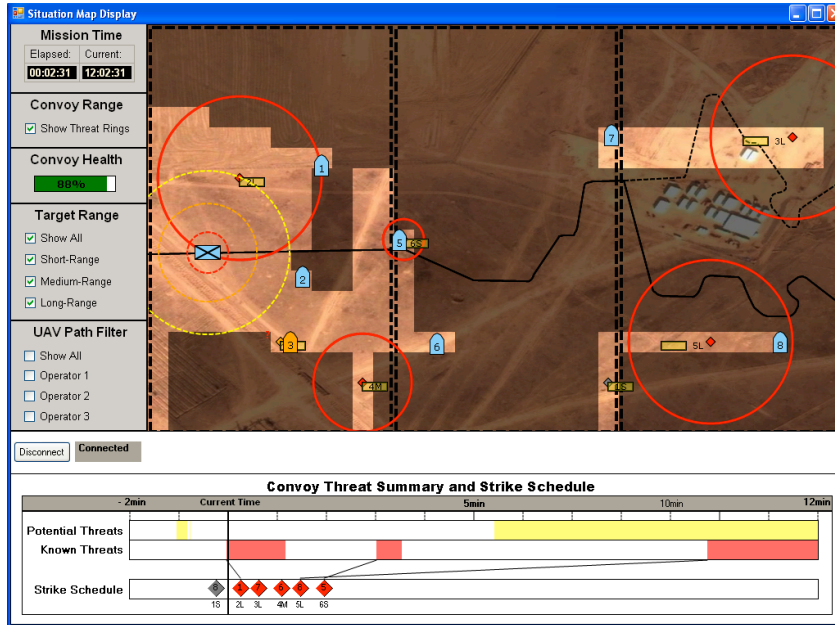
Indications from previous studies (Scott et al., 2006; Wan, 2007) and anecdotal evidence suggests that the location of the interactive event timeline aspect of the IRA tool on a peripheral display that is on a different visual plane than the main task display may not be ideal. Participants had to look back and forth between different displays in order to use the interruption recovery assistance. This takes time to visually orient to the view, and as participants in Wan's (2007) study claimed, is distracting and annoying. This chapter addresses this issue by proposing an alternative design that integrates IRA tool into the main task display.

As discussed in Chapter 3, Wan's research investigated the integration of event replay capabilities in the main task display context (i.e. a red X on the map display to show the location of a past event) in comparison to Scott et al.'s IAI which used the event replay feature together with the control features on a peripheral display. The design discussed in this chapter, completes the design evolution by integrating both the event replay capabilities and the control features (i.e. the interactive timeline) on the main task display. The following sections describe the new design and integration technique for each IRA bookmark.

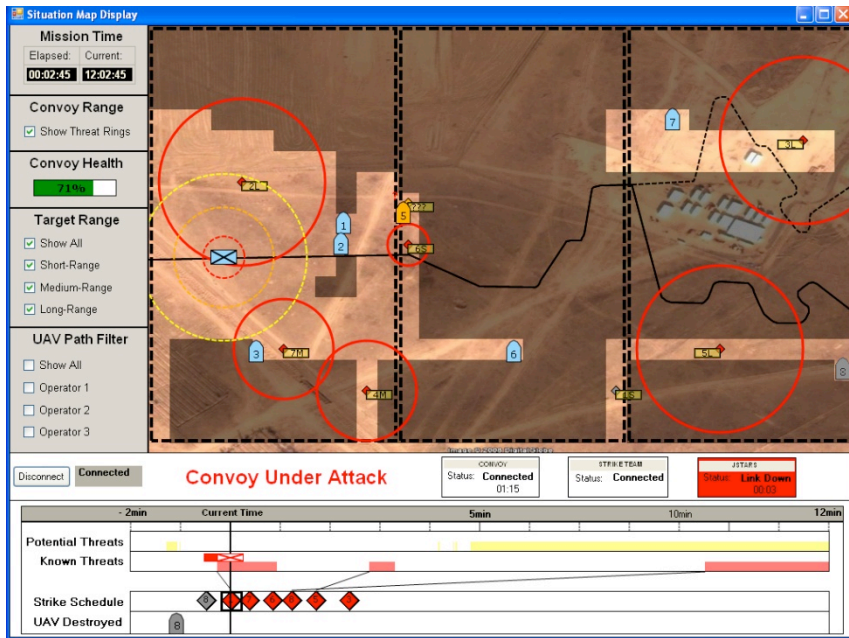
5.1 IRA Integration

The Map Display was chosen to contain the new IRA because observation of the first study showed that people spent most of their time attending to the Map Display. More specifically,

IRA's interactive bookmarks discussed in Section 3.5, namely: convoy attacked, UAV destroyed and late strikes, were integrated into the threat summary and strike schedule timeline at the bottom of the MD and the communication link status event bookmarks were added at the top of this timeline (see Figure 16).



(a)



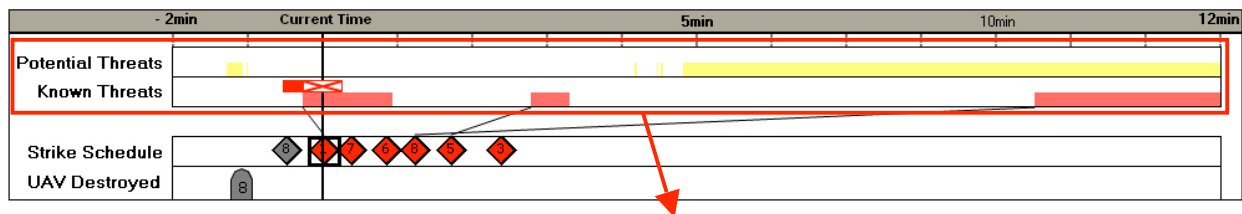
(b)

Figure 16. Map Display: (a) without integrated IRA (b) with Integrated IRA

The trade-off for integrating the IRA into the threat summary timeline is that by doing that the 10-minutes of history provided on the IRA would be reduced to 2-minutes of history. Although the timeline could be altered to show more history, the post-experimental interview in the first study, showed that participants are mostly concerned with the more immediate situation and they claimed to rarely use the history. Instead, they found the strike schedule and the lines connecting the targets to their threat box very useful. In real life, interruptions may differ in length, but since we used 2-minutes interruptions, for the purposes of this research the 2-minutes history was not changed.

5.2 Convoy Attacked

The convoy attacked event bookmark was displayed in the potential and known threat rows of the timeline because the priority of attending to a convoy attack overrides any urgency to provide potential or known threat awareness (see Figure 17). Both potential threats and known threats rows were divided in half. The top half shows the convoy attacked event bookmark and the lower half displays the threat boxes. The convoy attacked event bookmark appears in the proper row to differentiate if a known vs. potential target attacked the convoy. Since the convoy attacked bookmark is made smaller in compare to the last design of the IRA and since it may clutter the known threats row, a convoy attack message will be triggered above the timeline every time the convoy is under attack (see Figure 18).



Threats rows and Convoy Attacked event bookmark

Figure 17. Convoy attacked bookmark integrated into the potential and known threats rows

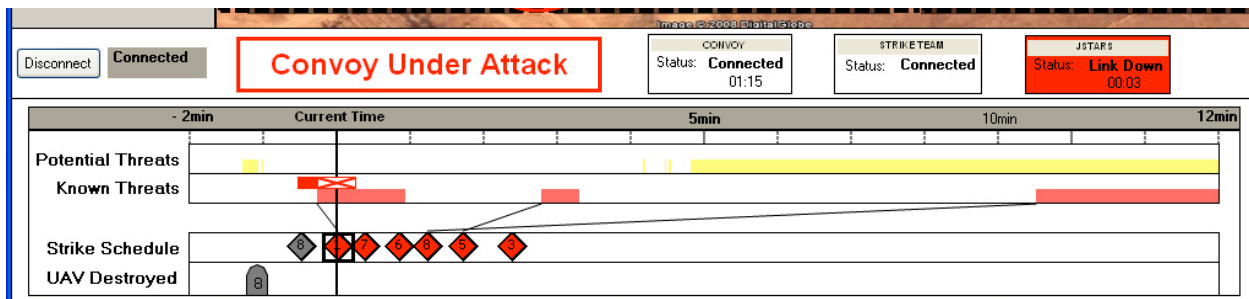


Figure 18. Convoy under attack warning message

The event bookmark also supports the event replay. Selecting the event bookmark causes a red “X” to be displayed in the location on the map where the convoy was attacked.

5.3 UAV Destroyed

An extra row was added to the bottom of the timeline to show the UAV destroyed event bookmarks (see

Figure 19). Event replay was also supported with these event bookmarks; thus selecting these bookmarks shows the location where the corresponding UAV was destroyed.

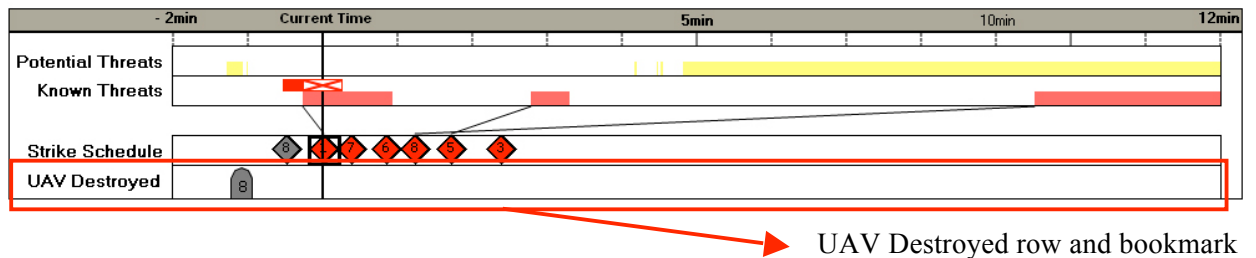


Figure 19. UAV destroyed row and bookmark

5.4 Late Strikes

As discussed in Chapter 2, a late strike refers to a scheduled strike that will occur after the convoy is or expected to be in the attack range of a target (i.e. known threat). In the previous version of the IRA, selecting a late strike event bookmark on the IRA timeline highlighted the corresponding target on the convoy threat summary and strike schedule timeline on the Map Display (e.g. the line connecting the target to its threat box became bold and a square with bold lines were displayed around the target). In the integrated version of the IRA, the late strike targets are automatically highlighted on the timeline using a bold box around the target icon on the timeline (see Figure 20).

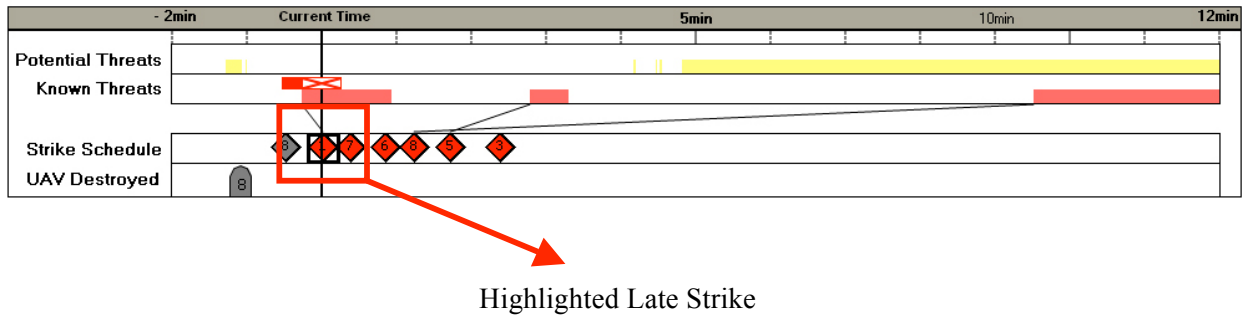
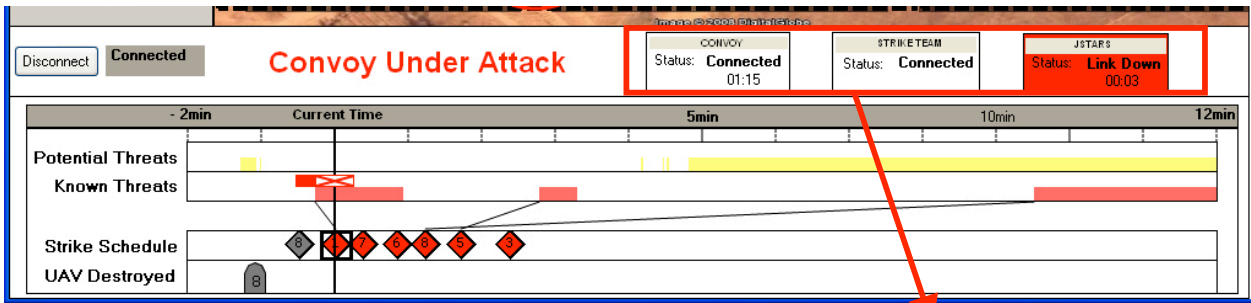


Figure 20. Late Strikes get highlighted automatically

In the previous design of the threat summary and strike schedule timeline, the number inside each target represented the UAV that discovered the target and the target number and attack range was displayed below the icon. This icon design was reported as problematic in study 1, since participants only really cared about the target number. The new design of the IRA includes the target number inside each target icon and excludes the UAV number and target range.

5.5 Communication Link Status

The post-experimental interview in the study 1 showed that most of the participants used the more visual communication link status diagram included in the Mission Status Display instead of communication link status information available on the IRA timeline. Because of that, the new design of the IRA tool includes a more visual summary of the communication link status in a separate section at the top of the timeline (see Figure 21).



Communication Link Status

Figure 21. Communication link status information

Three separate boxes were used to show the communication link status to the convoy, strike team and the JSTARS. Whenever the communication link to an external source is disconnected, its corresponding box changes color to red and the status message inside the box changes to “Link Down.” A timer is also displayed at the bottom of the red boxes that shows the duration of a link disconnection. As communication link gets connected, the corresponding box changes color to nominal white and the status changes to “connected”. The timer in the connected box then shows when the last disconnection happened.

The next chapter describes a user study designed to evaluate the re-design of the IRA tool integrated into the Map Display. For the purpose of comparison, the experiment uses the same experimental design used in the baseline study (Study 1).

Chapter 6

User Study 2: Evaluation of the IRA Location

In order to evaluate the new IRA design discussed in Chapter 5, a second laboratory-based user study was conducted. The goal of the user study was to see if the new IRA integrated into the main displays, as opposed to the IRA timeline located on a separate display, would improve the mission commander's interruption recovery. The experimental design was held constant to Study 1, with the intention to compare the results. Chapter 4 provides a detailed explanation of the task scenarios, interruption task, apparatus and the procedure used in the study. This chapter discusses the revised study hypotheses and the data analysis from the second study, as well as the trends across the series of studies that have been conducted.

6.1 User Study Hypotheses

As discussed above, the main goal of this study is to evaluate the alternative design of the IRA tool. This study uses the same independent variables as Study 1, as discussed in Chapter 4, namely the assistance type and decision accuracy. However, unlike Study 1 which compared IRA assistance with no assistance, in this study the assistance type variable refers to the type of interruption recovery assistance that the subjects were provided: separate or integrated. Separate assistance type refers to the IRA timeline being available on the Mission Commander Display, as described in Chapter 4. Integrated assistance type refers to the IRA being integrated into the Map Display, as described in Chapter 5.

Since Study 1 provided evidence for effectiveness of the IRA in reducing the interruption recovery time, and since participants reported the location of the IRA on a separate display as distracting, it is logical to expect that integrating the IRA into the main displays would further reduce the interruption recovery time.

Hypothesis 1: Integrated IRA helps minimize the interruption recovery time of the mission commander after an interruption.

As discussed in Chapter 4, decision difficulty refers to the difficulty of the decision faced after an interruption: simple or complex. Simple decision difficulty refers to only one possible solution for the current situation. Complex decision difficulty refers to multiple possible solutions to the situation, but based on past events only one solution best meets the mission criteria.

Participants in Study 1 reported using the threat summary and strike schedule timeline as a rich situational awareness tool. The results of the Study 1 also showed that the event bookmarks on the IRA improved decision accuracy. Since the new design of the IRA integrates the event bookmarks into that timeline, it may provide even greater utility especially after the interruptions.

Hypothesis 2: Integrated IRA helps the mission commander to make more accurate decisions, especially in complex situations.

6.2 Participants

Fourteen computer-literate participants (9 Male, 5 Female), were recruited from the MIT community. All 14 participants were students with some military training, including those

currently enrolled in Reserve Officers' Training Corps (ROTC) program at MIT, those who had graduated from military academies like Air Force Academy, or those who were current active duty officers. Participants received \$30 remuneration and they were told that the best performer would receive \$100 gift card.

6.3 Results

For the data analysis, participant's interruption recovery time was first examined. The effect of the independent variables (decision difficulty and assistance type) on interruption recovery time was investigated, along with their interaction, in a two factor repeated measures ANOVA.

The results of the ANOVA showed that neither of main effects was statistically significant. For assistance type, the location of the IRA timeline did not significantly affect the recovery time ($F(1,12) = 0.0812, p = .7769$). The participants' recovery time was also not significantly different between simple and complex decisions ($F(1,12) = 0.3778, p = .059$). The analysis did show, however, a highly significant interaction effect between assistance type and decision difficulty ($F(1,12) = 9.457, p = 0.004$). This makes it difficult to cleanly interpret the main effects of the two factors. An in depth statistical analysis of the interaction effect is described in Appendix J. The main finding of this analysis suggests a trend for negative effects of the integrated IRA on recovery time when the mission commander faced a simple decision and a trend for positive effects of integrated IRA on recovery time when the mission commander had to make a complex decision.

Since the decision accuracy data was binary, non-parametric testing was used on these data. In this case, similar to Study 1, the most appropriate test appeared to be McNemar's test. Similarly, the simple and complex decision data were analyzed separately. McNemar's test with the continuity correction showed no significant difference between decision accuracy for simple decisions across assistance types (Chi squared = 0.5, $p = .479$). In addition, No significant difference was found for complex decision accuracy across assistance types (Chi squared = 1.125, $p = .288$).

As discussed earlier, the experimental design of this study was held constant in order to allow comparison to Study 1. Both studies also share a common assistance type (IRA on a separate display). Comparison between Study 1 (the baseline study) and this study showed that the recovery time data gathered from Study 2 is fairly consistent statistically with the data gathered from the assistance condition of the Study 1 (see Figure 22). Consequently, it seems that both the separate and integrated IRA tools still provide significant utility in recovering from interruptions in comparison to providing mission commander no interruption recovery assistance.

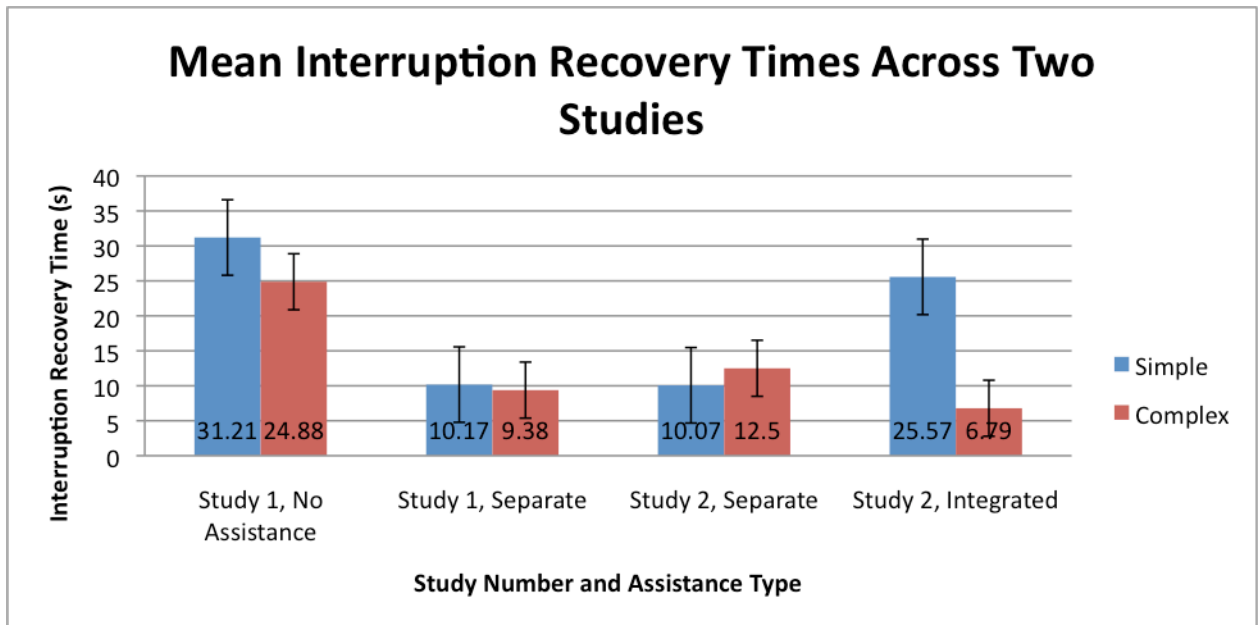


Figure 22. Comparison of recovery time data across the two studies

6.4 Discussion

The implications of these results are interesting. Previous experiments found that the tool shows promise for assisting interruption recovery at a supervisory-level in command and control setting. This experiment was conducted primarily because of conflicting results in past work that suggested both that the separate display was distracting and detrimental to participants' recovery time and that it was not. The goal of this study was to clarify this contradiction. In the post-experimental interview most of the participants said they preferred the integrated version and in fact they claimed that they liked the separation between the command interface (input) and situational awareness displays (output). However, we found no significant difference attributed to the location of the tool on the displays or of the difficulty of the decision presented to the user. This suggests that people did not perceive the interactive feature of the IRA as a command feature. One explanation for this is that the type

of command provided on the Mission Commander Display modifies the scenario behavior (e.g. stopping the convoy), whereas the interactive bookmarks on the IRA only change the level details in the visualization (e.g. showing a red “X”).

An evaluation of the results across the series of studies resulted in interesting findings. A highly consistent trend in interruption recovery assistance between different decision difficulties were seen across Scott et al.’s (2006) IAI study, Wan’s (2007) IRA study and the Study 2 described in this thesis. The trend suggests that the interruption recovery assistance causes better recovery for complex decisions but hinders interruption recovery for simple decisions. Ideally an interruption recovery tool should aid recovery for a broad range of decisions and situations, and at the very least, not hinder decision-making. Although Study 2 was conducted with the hope that the integrated IRA would address this issue, the same behavior was observed again. One possible reason for the slow recovery times for the simple decision case is that the participants may not have felt as rushed or pressured to make the decision after the interruption only because the decision was straightforward and as a result they spent more time gathering all the information they could from the interface and acted on their decision at the last minute.

Chapter 7

Conclusions and Future Work

This research presents an investigation of interruption recovery assistance for supervisors in time-critical work environments such as emergency response and command and control. This research extends previous work by Scott et al. (2006) and Wan (2007).

7.1 Research Objectives and Findings

The goals of this research were to address the following objectives:

- Investigate the limitations of previous design of the Interruption Recovery Assistant (IRA) tool in the previously developed experimental platform
- Investigate potential improvements to the design of software tools that help mitigate interruption recovery of team supervisors in command and control
- Investigate the process of studying interruption recovery with user-based experimental methodology.

Two user studies to evaluate the effectiveness of interruption recovery assistance in mitigating the negative effects of interruptions were described in this thesis. The first study addressed the experimental platform limitations used in the initial investigations of the IRA tool, developed by Wan (2007). The results of this were important in that they showed significant decrease in recovery time of the mission supervisors while using IRA (see Chapter 4). The study also showed significant increase in supervisor's decision accuracy with the presence of IRA. As hypothesized, the perceived utility of the IRA tool was increased by

making the scenarios more challenging and by creating a more realistic experimental platform. Since supervisory-control tasks in real life are typically cognitively challenging, any simulation of these tasks or the systems involved should enforce a comparable cognitive demand. In general the result indicated the importance of having a good external validity in studying complex systems.

The second study addressed the design limitations of IRA. In particular, the original IRA tool was compared to the redesigned IRA tool. The redesigned tool addressed the fact that the original IRA tool provided interruption assistance on a peripheral display, which can distract from the main task. In order to address this issue, the IRA event timeline was integrated into the large-screen wall displays, which serve as the primary task displays in the experimental task environment (see Chapter 5). The hypothesis was that including both control and event replay on the main display minimizes the distraction associated with using the IRA tool during task resumption.

Although it may appear that the IRA tool could be incorporated into either of the two interfaces (Map Display, or Mission Commander Display) without significant impact to recovery time or decision accuracy, however considering the fact that there was an interaction effect which was consistent with the trend seen for the previous studies, we can't be confident in this conclusion and more investigation is warranted. The quantitative data supports the fact that for complex decisions it does not really matter where the interruption recovery assistance is located on the screen but for simple decisions, the integrated version may hinder the interruption recovery performance. On the other hand, based solely on user preference as determined in the post-experimental interview, it seems that most participants

found the tool more useful when it was integrated into the Map Display so that they had all their situational awareness information on one screen, which was separated from their command inputs. This makes the case that this location for the tool is user-friendlier, and since no statistical difference in performance results was found, would be a good place to implement it.

In conclusion, this research contributes new empirical results, from two user-studies, on the effectiveness of an interruption recovery software tool in a time-critical environment. It also provides a methodological contribution in the refinement of an experimental design for computational interruption recovery assistance in dynamic, time-critical environments. This paves the way for similar studies to investigate interruption recovery in such environments.

7.2 Limitations and Future Work

Given the inconsistencies shown in the series of user studies and especially the significant interaction between the main effects in the final user study, more investigation and in depth analysis is warranted. This investigation could be critical in accurately understanding the experimental results discussed in this thesis. Participants in both user studies claimed that they not only used IRA for interruption recovery but they also used it to gather general situational awareness information. More investigation is needed to evaluate the co-existence of the integrated IRA on the Map Display and IRA on the Mission Commander Display. A mix of interruptions with different lengths may also show interesting results.

In addition, the usage of the Remote Assistance Display is still lacking. Introducing more functionality in RAD and creating a sufficiently complex task would make RAD more distracting and may lead to a better simulation. More specifically the simulated operators

requesting assistance could be treated as an interruption itself. Using real people (confederates) to play the role of the operators in a follow-up user study may also create a more realistic teamwork environment and hence may affect the participant's behavior. The improvements made to Scott et al.'s (2006) experimental platform discussed in Chapter 3 were a small step in evaluating a command and control setting. The investigation of tasks involved in a real military setting would help to identify the important events that could be captured, and therefore tracked by an interruption recovery tool such as IRA. Such knowledge could guide interface designers' decisions about the type of events and the level of details to be visualized in such a tool. Applying the experimental platform in a real military command and control center and observing the actual effectiveness of an IRA-like tool in a variety of situations at a variety of different complexities could fill the gap between reality and simulation.

Finally, as discussed in Section 6.4, a trend was seen across the studies that suggest that interruption recovery assistance negatively affected the recovery time for simple decisions. One approach to investigate this issue is to provide interruption recovery assistance only for complex decisions or perhaps an adaptive approach that provides assistance only when necessary.

Appendix A

Consent to Participate in Non-biomedical Research

Investigating Team Supervision Interfaces in Collaborative Time-Sensitive Targeting Operations

You are asked to participate in a research study conducted by Professor Stacey D. Scott (faculty supervisor) from the Department of System Design Engineering at the University of Waterloo, Professor Mary Cummings Ph.D, (Collaborator) from the Aeronautics and Astronautics Department at the Massachusetts Institute of Technology (M.I.T.) and Farzan Sasangohar (student investigator) from the Department of System Design Engineering at the University of Waterloo. You were selected as a possible participant in this study because the expected population this research will impact is expected to contain men and women between the ages of 18 and 50 with an interest in using computers with possible military or military-in-training experience. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

PARTICIPATION AND WITHDRAWAL

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The student investigator may withdraw you from this research if circumstances arise which warrant doing so.

PURPOSE OF THE STUDY

The overall objective of this study is to evaluate the effectiveness of a set of team supervision displays in facilitating decision making in collaborative time-sensitive targeting (TST) operations. The goals of this study are twofold. The first goal is to evaluate the proposed displays' effectiveness for supporting the supervisory role of a mission commander in collaborative TST mission operations. The second goal is more general and involves exploring some of the open questions in the new research approach of providing activity awareness to help further our understanding of these types of displays, which in turn will help us improve our supervisor displays. Evaluation of the effectiveness of these interfaces will be measured through subject performance on their decision-making tasks and

the subjects' situation awareness which is generally defined as the perception of the elements in the environment, the comprehension of the current situation, and the projection of future status of the related system. This research is intended to explore activity awareness displays used to support the supervision of a team of operators engaged in the human supervisory control of multiple unmanned aerial vehicles.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things individually:

- Each participant begins by completing an informed consent form and a background questionnaire that gathers participants' demographic information.
- Attend training and practice session to learn a video game-like software environment that will have you monitoring the ongoing performance of a team of operators under your supervision and intervening with certain command actions when mission performance begins to degrade. Your team of operators will be supervising and interacting with multiple unmanned aerial vehicles to achieve the goals of your overall mission.
- Practice on the software environment will be performed until an adequate level of performance is achieved, which will be determined by your demonstration of basic proficiency in monitoring the ongoing mission and the performance level of your team, in executing intervention command decisions such as assigning a spare operator to a certain critical mission region or holding back a convoy which you are tasked with keeping safe through a hostile region, and in detecting potential unsafe situations for the convoy (estimated time 1 hour).
- Execute four trials consisting of the same tasks as above, potentially in collaboration with other study participants (estimated 90 mins).
- Attend a semi-structured interview with the student investigator to determine your reactions to the software interfaces (estimated time 15 minutes).
- Attend a debrief session (5 minutes).
- All testing will take place in MIT building 35, room 220.
- Total time: 2-3 hours, depending on skill level.

POTENTIAL RISKS AND DISCOMFORTS

There are no anticipated physical or psychological risks in this study.

POTENTIAL BENEFITS

While there is no immediate foreseeable benefit to you as a participant in this study, your efforts will provide critical insight into the human cognitive capabilities and limitations for people who are expected to supervise multiple complex tasks at once, and how decision support visualizations can support their task management.

PAYMENT FOR PARTICIPATION

You will be paid \$30 to participate in this study which will be paid upon completion of your debrief. Should you elect to withdraw in the middle of the study, you will be compensated for the hours you spent in the study.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. You will be assigned a subject number which will be used on all related documents to include databases, summaries of results, etc. Only one master list of subject names and numbers will exist that will remain only in the custody of Professor Cummings.

IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact the Principal Investigator, Mary L. Cummings, at (617) 252-1512, e-mail, missyc@mit.edu, and her address is 77 Massachusetts Avenue, Room 33-305, Cambridge, MA, 02139. The faculty supervisor is Stacey D. Scott and she may be contacted by telephone at (519) 888-4567 x32236 or via email at s9scott@uwaterloo.ca. The student investigator is Farzan Sasangohar and he may be contacted by telephone at (617) 229-9097 or via email at fsasango@uwaterloo.ca.

EMERGENCY CARE AND COMPENSATION FOR INJURY

In the unlikely event of physical injury resulting from participation in this research you may receive medical treatment from the M.I.T. Medical Department, including emergency treatment and follow-up care as needed. Your insurance carrier may be billed for the cost of such treatment. M.I.T. does not provide any other form of compensation for injury. Moreover, in either providing or making such medical care available it does not imply the injury is the fault of the investigator. Further information may be obtained by calling the MIT Insurance and Legal Affairs Office at 1-617-253-2822.

RIGHTS OF RESEARCH SUBJECTS

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E32-335, 77 Massachusetts Ave, Cambridge, MA 02139,

phone 1-617-253-6787. This project was also reviewed and received ethics clearance through the University Of Waterloo Office of Research Ethics. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext., 36005.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above and my questions have been answered to my satisfaction. I have been given a copy of this form.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Name of Subject

Name of Legal Representative (if applicable)

Signature of Subject or Legal Representative

Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

Signature of Investigator

Date

Appendix B
Collaborative TST Demographic Survey

1. Age: _____
2. Gender: Male Female
3. Native Language: _____

If native language is not English:

English Proficiency:

- Low
- Moderate
- High

4. Occupation: _____

If student:

- a. *Class Standing:* Undergraduate Graduate
- b. *Major:* _____

If currently or formerly part of any country's armed forces:

- a. *Country/State:* _____
- b. *Status:* Active Duty Reserve Retired
- c. *Service:* Army Navy Air Force Other _____
- d. *Rank:* _____
- e. *Years of Service:* _____

5. **Have you had experience with remotely piloted vehicles (land, sea, air)?**
- Yes
- No

If yes:

a. Vehicle type(s)/class(es):

b. Number of hours: _____

6. Have you had experience supervising a team of operators piloting vehicles (land, sea, air)?

Yes

No

If yes:

b. Vehicle type(s)/class(es):

c. Responsibilities as team supervisor:: _____

d. Size of teams: _____

e. Number of hours: _____

7. Do you have experience supervising a team of people in other time-critical situations

Yes

No

If yes:

f. Types of time-critical situations:

g. Responsibilities as team supervisor:

c. Size of teams: _____

d. Number of hours: _____

8. Do you have experience supervising a team of people in other non time-critical situations

Yes

No

If yes:

h. *Types of non time-critical situations:*

i. *Responsibilities as team supervisor:*

c. *Size of teams:* _____

d. *Number of hours:* _____

9. How often do you play video games?

- Never
- Less than 1 hour per week
- Between 1 and 4 hours per week
- Between 1 and 2 hours per day
- More than 2 hours per day

10. Are you color blind?

- Yes
- No

If yes:

Which type of color blindness (if known) _____

Appendix C

Consent for Videotaping

Consent for Videotaping

As a participant in this study, I agree to being videotaped for the purpose of tracking my movement as well as a means of verifying results from other data collected. I am aware that I may withdraw this consent at any time without penalty, at which point, the videotape will be erased.

I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics, at 519-888-4567 ext. 36005.

Print Name

Signature of Participant

Dated at Cambridge, Massachusetts

Witnessed

Appendix D

Active Training in Practice Trial 1

[00:00] make sure the subjects understand that they may be within the target range of potential targets by telling them about the **yellow/orange/red gridnodes** on the map display (by turning on the convoy rings) and yellow **potential threat envelopes** on the activity timeline. Let them know that they can understand that they got attacked by looking at the IRA, Energy meter on MD and status messages on MSS.

[1:10] UAV 2 identifies a target. Talk to subjects about the changing color of the UAV to orange and the question mark beside it and that it should take only 30 minutes. Show them how they can check the identification time on the MSS. And let them know that they should use RAD after 30s.

[1:30-2:45] Communication to Convoy and JSTARS is gone. Let them know that they are in the target range of potential targets but since they are not losing health there is either no targets within the range or there are potential targets **but they don't attack**.

Since the convoy is approaching the known target (3S), subjects would try to hold the convoy but since the comm. is down they can't. Let them know that they can't trust the convoy commands (hold/release/reroute) and JSTARS. Show them the link status down on the Mission Status Summary and on the IRA.

[2:35] Convoy is in the target range of a short range target (3S). Show the subject the convoy's health level on the map display. Let them know that not every target attacks and that the algorithm calculates the probabilities of attack and chooses which target to attack.

[2:45] let them notice that the hold button is enabled. Show them the comm. Link status on MSS and IRA.

[2:45-4:00] The subject would hold the convoy since it's approaching a medium range target range. Talk to them about the late strikes for the three targets (3S, 4M, 5L) both on IRA and MD's activity bar and make sure they understand what the line to the right of threat envelope means. Make sure they **report the late strikes**.

UAV 2 is destroyed. Make sure they understand that and show them how they can use IRA to see the place where it got destroyed and make them notice that UAV 2 is added to the inactive UAVs list on MCI. Also show them the operator performance on MSS. Since they are approaching an un surveilled area, talk to them about their options to reroute an active UAV (UAV 1) to continue UAV 2's path but they have to wait until the target gets destroyed. Make sure they understand that targets attack multiple UAVs as long as they're alive. Finally, make sure that they use JSTARS to clear the path ahead.

[~3:57] Make sure they understand that they release the convoy because the line for 4M is now to the left of its target envelope.

[~4:30] should hold the convoy in order to avoid getting into the danger zone.

[~5:00] (In case they hold the convoy more than needed) make sure they understand that there is no need to hold the convoy for target (5L) since there is no late strike reported on IRA and the line is to the left of its threat envelope on the activity timeline on MD.

[~5:45] Let them know that their options are to either hold the convoy and let UAV 4 surveil the area or to use another JSTARS if they haven't already (Let the m know about the

advantage of using JSTARS which is to avoid the hold penalty). Make sure they understand that the only targets they need to hold the convoy for are the targets for which a late strike was reported on IRA and activity timeline on MD. Show them how to use IRA to see which target they should hold for. Show them their health score (~90%). Let them know that they got penalized for holding the convoy but the penalty is much smaller in compare to being attacked.







[~6:00] While they're holding the convoy, talk to them about their options to choose which path to continuo on. Let them know that the main path is unsurveilled and is more risky and the best decision would be to change path. Let them know about the possibility of changing path after the intersection and how the alternative path changes to solid. Note that threat envelope is updated accordingly both on map display and on IRA.

[~7:30] It is better to hold the convoy and let UAV4 identify the target. UAV4 is taking too long to identify. Let the subject practice using the RAD to help the operators. Let them know that they should keep track of identification times and if it's more than 30s they should use RAD to assist the operator.

[~10:30] Convoy is finishing the route but it's losing health. Make sure they understand that a potential target attacked them.

Appendix E

PowerPoint Tutorial

<p style="text-align: center;">Assisting Collaborative Time-Sensitive Targeting</p> <hr/> <p style="text-align: center;">Experimenter: Farzan Sasangohar Principal Investigators: M.L. Cummings, S.D. Scott Winter 2009</p> <div style="display: flex; justify-content: space-around; align-items: center;"></div>	<p style="text-align: right;"> Training Overview 2 of 51</p> <hr/> <p>There will be 3 phases of your participant training:</p> <ol style="list-style-type: none">1. Mission Summary & Mission Goals2. Introduction to the Experiment Displays3. Practice Sessions
<p style="text-align: right;"> Mission Summary 3 of 51</p> <hr/> <p>In this experiment, you will be in command of a team of unmanned aerial vehicles (UAV) operators engaging in a time-sensitive targeting (TST) operation. Your team's mission is to secure safe passage for an important political convoy through a hostile region.</p> <p>Your team's UAVs are equipped with camera sensors only (i.e., they have no weapons capabilities). Therefore, your UAV operators will be coordinating with an external air strike team to destroy any identified threats to the convoy in your team's area of interest (AOI).</p> <p>Your team's AOI will be divided into three sub-AOIs, each assigned to one of your UAV operators. To surveil these areas, these UAV operators each will be monitoring and interacting with a number of highly autonomous UAVs. You also have limited access to additional surveillance capabilities from JS-TARS (Joint Surveillance & Target Attack Radar System), a local multi-sensor aircraft, to supplement your team of UAVs.</p> <p>During the mission, interruptions may occur which will simulate realistic military environments in which a mission commander may be required to perform secondary tasks. The interruption may be short and occur directly in the scenario room, or the interruption may be longer and require you to leave the room.</p>	<p style="text-align: right;"> Mission Goals 4 of 51</p> <hr/> <p>The primary goals of this mission are to get the convoy through your AOI as quickly, and as safely as possible. Therefore, clearing threat-free paths for the convoy and keeping the convoy moving are your team's highest priorities.</p> <p>In order to support the military's larger objectives, your team has also been tasked with two additional mission objectives. The first will be to surveil the alternative road for safe passage of future convoys. The second will be to assist remote operators in target classification.</p> <p>Finally, as the mission commander, another priority of yours will be to monitor the performance of the strike team and to report any instances of unsatisfactory strike support. This will be defined in more detail later.</p>

Possible Command Interventions 5 of 51

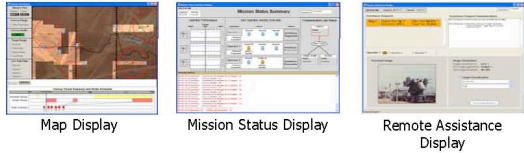
In order to achieve your mission objectives you will have four types of commands at your disposal:

1. Convoy commands: Hold position, release from holding.
2. Requesting additional surveillance information from a nearby intelligence source (JSTARS).
3. Reassigning a UAV from one part of the AOI to another to take over the surveillance activities of a UAV that has been shot down.
4. Rerouting the convoy to the alternative path.

The specifics of how and when to use these command interventions will be discussed later in this tutorial.


Experiment Displays: TST Supervisor Displays 6 of 51

Large-Screen Wall Displays



Map Display Mission Status Display Remote Assistance Display

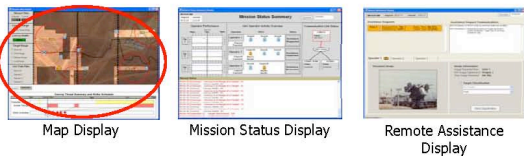
Tablet Display



Mission Commander Display


Experiment Displays: TST Supervisor Displays 7 of 51

Large-Screen Wall Displays



Map Display Mission Status Display Remote Assistance Display

Tablet Display

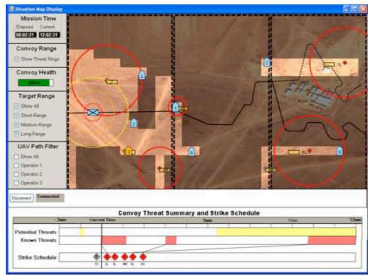


Mission Commander Display

Experiment Displays: TST Supervisor Displays 8 of 51

Map Display (cont'd)

The **map display** visualizes positional information of relevant contacts and assets in the context of your team's geographical area of interest (AOI). It also provides several tools for changing the level of detail displayed on the screen.



Threat	Type	Priority	Status	Time
Primary Threats				
Asset Threats				
Strike Schedule				

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Map Display (cont'd)

The main components of this display, described in detail next, are:

1. The mission clock.
2. A map of your team's AOI.
3. Filters for toggling certain display information.
4. A timeline indicating the current and expected threat level to the convoy.

1: Mission Clock

2: Map of AOI

3: View Filters

4: Threat Summary & Strike Schedule Timeline

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Map Display Alternate Path

Prior to each mission, two routes have been identified for the convoy to traverse. The convoy's current route is shown by a **black solid line**, while its alternate path is shown by a **black dotted line**.

As will be explained later, the convoy's current path can be changed between the two – but only **once**. It is recommended that this function only be used when **near the intersection of the two paths**. If it must be used after the intersection of the two paths has already been passed, the convoy will change direction and move **backwards** towards the intersection and then begin its new route.

Alternate Path

Current Path

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Map Display (1) Mission Clock

MISSION TIME	
elapsed:	current:
00:23:10	12:23:10

The Mission Clock shows the up-to-date mission times, including the **elapsed time** since the beginning of the test session and the **current mission time**.

This mission clock can be found in the upper left corner of all three experiment displays

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Map Display (2) Map: Geospatial Mission Activity

The Map shows the up-to-date geospatial mission activity within your team's AOI, see Map Symbology on the right for details.

The Map also indicates regions that have not yet been surveilled with a **transparent black overlay**.

Surveilling is the UAVs' default state. When a potential target is detected by a UAV's onboard automatic target recognition (ATR) system, an image is sent to the operator for review & confirmation (reviewing ATR imagery state). This process should only take 30 seconds, during which time the UAV loiters at that location. If the TargetID process **takes longer than 30 seconds**, you may choose to assist the operator using the Remote Assistance Display (make sure 30 seconds has elapsed).



If confirmed, the target is added to the strike schedule. A yellow label is attached to the target symbol to indicate its number and weapons range. When the target is selected, the label becomes opaque and easier to read. To select a target, simply touch (with your finger) its location on the map.

In the following example, the first target to be discovered would be numbered target 1. The "M" indicates that this target has been identified as having Medium weapons range capabilities.



If a UAV is lost (i.e. it is shot down by a live target), the UAV is grayed out at its last known location.

Map Symbology	
Convoy	
Convoy routes	(Man) (Operate)
UAV	(default) (showing ATR imagery) (down)
Targets	(Identified) (Identifying) (destroyed)
Operator AOI boundary	(nominal)

ATR = automatic target recognition
OPL = operator performance level



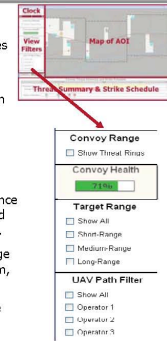
The View Filter panel provides toggle check boxes to enable you to display or hide certain information on the map. By default all toggles are set to the 'off' (i.e., 'hide') position.

To **show** the desired information, touch inside the check box. A checkmark will appear in the box and the corresponding information will appear on the map.

To **hide** the information, touch inside the checkbox again. The checkmark and corresponding map information will disappear.

Three types of view filters are available:

- 1. Convoy Range Filter:** this toggle shows or hides the distance range rings around the convoy corresponding to the expected range of short, medium, and long-range weapons in the AOI.
- 2. Targets Range Filter:** these toggles show or hide the range rings for any known (i.e., previously identified) short, medium, or long-range targets.
- 3. UAV Surveillance Path Filter:** these toggles show or hide the corresponding UAV flight paths.



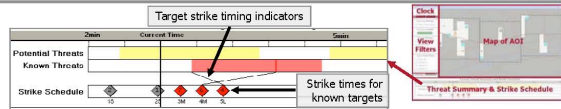
The Threat Summary & Strike Schedule timeline displays the temporal relationship between the **scheduled target strikes** and the **known and potential threats to the convoy**.

In particular, the timeline displays red & yellow threat envelopes, corresponding to known threats & potential threats, respectively. The width (duration) of a threat envelope indicates the length of time the convoy is expected to be within range of that threat, based on the convoy's speed and path, and the position and weapons range of that threat.

Red/known threat envelopes correspond to periods of time when the convoy will be within range of **identified targets**. Most of these targets should be destroyed by the strike team before the convoy comes within their range (discussed in more detail later). When two or more known threat envelopes overlap, a darker red is shown on the timeline.

Yellow/potential threat envelopes correspond to periods of time when the convoy will be within expected weapons range of an **unsurveilled area**, which may contain a target.

Each time the convoy enters a threat envelope (i.e., comes within weapons range of a known or possible target), the convoy **may** be attacked. Each time the convoy is attacked, first its health level will decrease by 10-15% and then it will decrease by 1% for every second the convoy remains in the range of the target. **If the convoy is in the range of multiple targets: it will lose health multiple times.** The convoy will report its energy level after each attack. **When the convoy's energy level reaches 0, the mission is over!** (continued on next slide...)

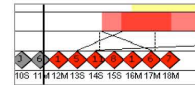


The third (lowest) row of the timeline displays the target strike schedule for identified targets. Each diamond in the strike schedule represents a known target. The numeric label inside a target corresponds to the UAV (or external intelligence team) who discovered it.

The target ID is provided below each target as an alphanumeric tag indicating the target number and its weapons range capability (S=short, M=medium, L=long). The target's position on the strike schedule represents the expected time the strike team will destroy the target.

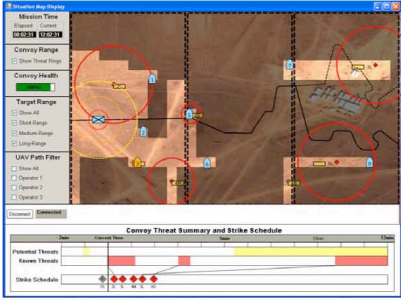
A black line connects each target to the **start** of its corresponding threat envelope (i.e., expected time the convoy will be within weapons range of that target if the target is not destroyed beforehand). These lines indicate whether the strike team is prosecuting targets quickly enough to maintain the safety of the convoy.

If a **target is located to the left** of its threat envelope the convoy will be safe. For example, target 135 & 145 in the schedule to the right will be destroyed before they can harm the convoy. However, target 17M will be destroyed slightly after it could harm the convoy.



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Any Questions?

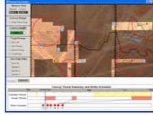


Advance slide when you are ready...


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Experiment Displays: TST Supervisor Displays

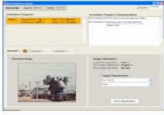
Large-Screen Wall Displays



Map Display




Mission Status Display



Remote Assistance Display

Tablet Display

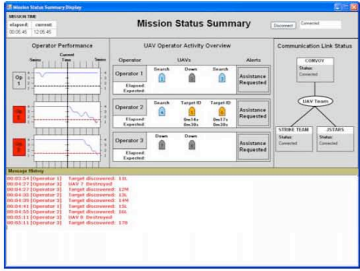


Mission Commander Display

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Mission Status Display

The **Mission Status Display** visualizes current and expected mission status information, which includes surveillance progress for each UAV operator and given areas of interest and communications link status to external resources

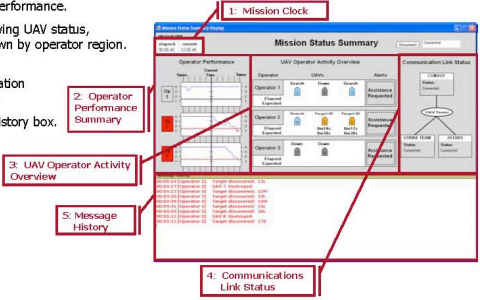


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Mission Status Display

The main components of this display, described in detail next, are:

1. The mission clock.
2. Graphs summarizing operator performance.
3. Panel showing UAV status, broken down by operator region.
4. Current communication link status.
5. Message history box.





Mission Status Display
(1) Mission Clock

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MISSION TIME	
elapsed:	current:
00:23:10	12:23:10



The Mission Clock shows the up-to-date mission times, including the **elapsed time** since the beginning of the test session and the **current mission time**.

This mission clock can be found in the upper corners of all experiment displays



Mission Status Display
(2) Operator Performance Summary

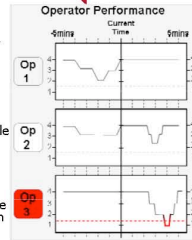
22 of 51

The Operator Performance Summary panel displays operator surveillance performance (in relation to convoy safety) for the past and future 5-minute periods.

The operator performance level (1-4) reported at each time period is based on the following heuristic:

- 4 - **Probable convoy safety level is high** - all areas within expected weapons range have been or are expected to be surveilled
- 3 - **Probable convoy safety level is somewhat uncertain** - convoy within or expected to be within long-range weapons distance to unsurveilled areas
- 2 - **Probable convoy safety level is very uncertain** - convoy within or expected to be within medium-range weapons distance to unsurveilled areas
- 1 - **Probable convoy safety level is low** - convoy within or expected to be within short-range weapons distance to unsurveilled areas

Performance level 4 is ideal. Performance below this is undesirable but minimally acceptable until it reaches level 1, which is considered 'unacceptable' because the convoy is (or will be) entering directly into an unsurveilled area. When performance drops to level 1, the dotted line, the plot line, and the Operator label will be displayed in **red** to indicate this critical state. This panel is a good indication of past and future operator performance for each region. You may use this information to determine which of the operators need additional assistance.



Mission Status Display
(3) UAV Status Activity Overview

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The UAV Status Activity Overview panel displays the current state of all UAVs (which can be Search, Target ID, Down).

The timer below the TargetID UAV's keeps track of how long the UAV has been loitering (in order to identify targets).

One thing to keep track of is the Elapsed time when a UAV is loitering (orange). If the elapse time becomes longer than 30 seconds, you may want to assist the operator by using the Remote Assistance Display (see detailed instructions in next section).

Note that when the Assistance Request is accepted by the operator, the Operator panel will turn orange. Please note that here the Blue UAVs are searching, the orange UAVs are identifying and the gray UAVs are destroyed.



Mission Status Display
(4) Communications Link Status

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The Communications Link Status panel displays the current status of your UAV team's communication connections to external contacts:

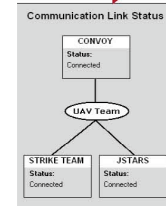
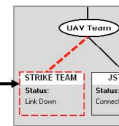
- Convoy, Strike team, & JSTARS (your external intelligence source)

When the line connecting the UAV Team oval and one of the external contacts is solid black, there is a strong connection. When the connection line is broken (i.e., dotted) and red, the communications link is down.

Each box representing the external contacts displays:

- Contact name
- Current communication status

Communication between UAV team and Strike team is down.



(continued on next slide...)

Mission Status Display
(4) Communications Link Status (cont'd)

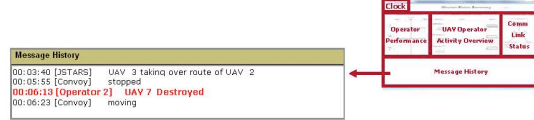
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When a communication link is down, your team will not be able to communicate with the corresponding external contact. Consequently, certain mission actions will be unavailable while that link is down. The unavailable actions resulting from each external link failure are as follows:

- **Convoy:** holding, releasing, or changing the convoy's path
- **Strike Team:** scheduling a strike for a newly identified target (once the link is re-established, strikes for such targets will automatically be scheduled)
- **JSTARs:** obtaining additional surveillance

Mission Status Display
(5) Message History

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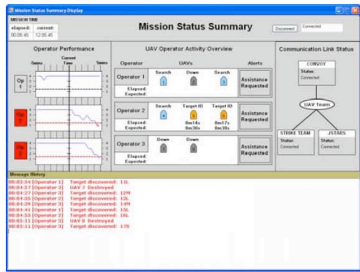


The Message History displays a scrollable list of status and communication messages from team members, external contacts (e.g., the convoy, intelligence sources), and system messages.

Each message begins with a time-stamp indicating when it was received and a label indicating the message source. Messages identified as critical by the system are displayed in red. Sample messages:
 12:28:27: [Strike Team] Target 3M scheduled to be destroyed at 12:31:00.
 12:30:15: [System] Convoy entering weapons range of target 3M!
 12:30:35: [Convoy] Under attack!
 12:31:30: [Convoy] Damage report: energy level at 80%.

Any Questions?

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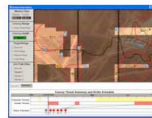


Advance slide when you are ready...

Experiment Displays: TST Supervisor Displays

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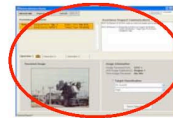
Large-Screen Wall Displays



Map Display



Mission Status Display



Remote Assistance Display

Tablet Display



Mission Commander Display



Mission Status Display (4) Communications Link Status (cont'd)

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When a communication link is down, your team will not be able to communicate with the corresponding external contact. Consequently, certain mission actions will be unavailable while that link is down. The unavailable actions resulting from each external link failure are as follows:

- **Convoy:** holding, releasing, or changing the convoy's path
- **Strike Team:** scheduling a strike for a newly identified target (once the link is re-established, strikes for such targets will automatically be scheduled)
- **JSTARs:** obtaining additional surveillance



Mission Status Display (5) Message History

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```

Message History
00:03:40 [JSTARs] UAV 3 taking over route of UAV 2
00:05:55 [Convoy] stopped
00:06:13 [Operator 2] UAV 7 Destroyed
00:06:23 [Convoy] moving
    
```



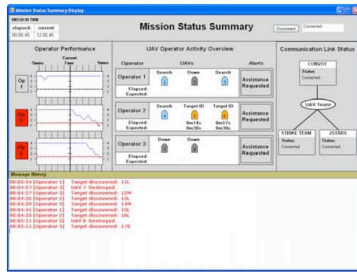
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Each message begins with a time-stamp indicating when it was received and a label indicating the message source. Messages identified as critical by the system are displayed in red. Sample messages:
 12:28:27: [Strike Team] Target 3M scheduled to be destroyed at 12:31:00.
 12:30:15: [System] Convoy entering weapons range of target 3M!
 12:30:35: [Convoy] Under attack!
 12:31:30: [Convoy] Damage report: energy level at 80%.



Any Questions?

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Advance slide when you are ready...



Experiment Displays: TST Supervisor Displays

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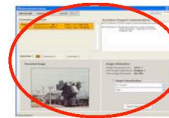
Large-Screen Wall Displays



Map Display



Mission Status Display



Remote Assistance Display

Tablet Display



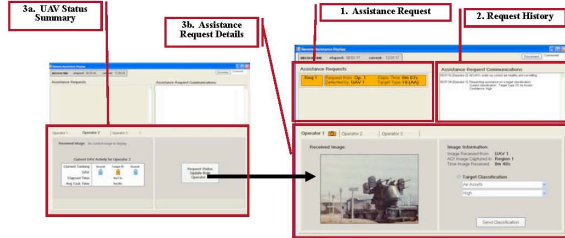
Mission Commander Display

Remote Assistance Display (RAD) allows the mission commander to **assist the remote UAV operators who are taking too long (>30 seconds) to perform the target identification task.**

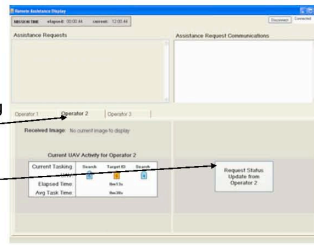


The main components of this display are:

1. Assistance Request.
2. Request History.
3. UAV Status Summary or Assistance Request Details (invoked by clicking "Request Status Update from Operator X" in UAV Status Summary) .

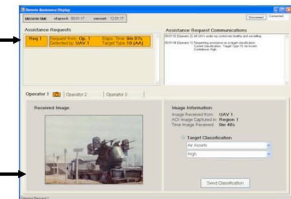


When any of the UAVs are in the process of TargetID, the Mission Commander may assist the operator by selecting the corresponding Tab of the Operator number and clicking on "Request Status Update From Operator X".



After the "Request Status Update From Operator X" has been clicked, there will be a short delay (communication lag time) and then the request will be added to the Assistance Request box.

By clicking the request box, the target image details will appear.

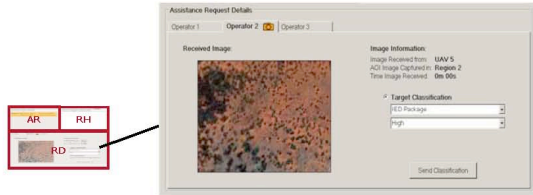




Remote Assistance Display (3) Request Details

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For each assistance request, the details displayed include: UAV, time received, Target Classification, and Target image.
It is your responsibility, as the mission commander, to match the target classification to the image, to the best of your ability.



Remote Assistance Display Target Classifications

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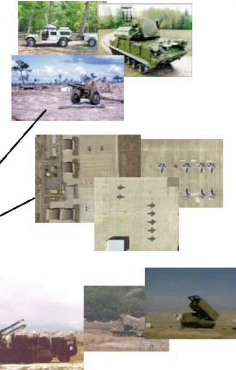
The following information will help you aid your team members in identifying targets.

Targets are primarily classified by their range – short, medium or large. Here are some examples:

Short - Vehicle Mounted Artillery, IEDs (disguised as packages or vehicle), Ground Artillery, and Military Vehicles (tanks, stationary vehicles)

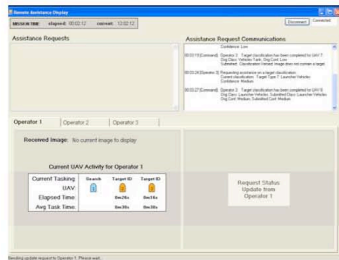
Medium – Air-Based Assets (Jets, Airplanes, Helicopters)

Long – Missile Launchers (Rocket launcher)



Any Questions?

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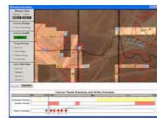
Advance slide when you are ready...



Experiment Displays: TST Supervisor Displays

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Large-Screen Wall Displays



Map Display



Mission Status Display



Remote Assistance Display

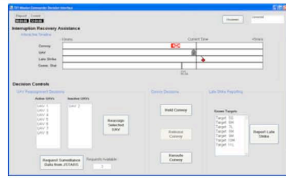
Tablet Display



Mission Commander Display

Mission Commander Display

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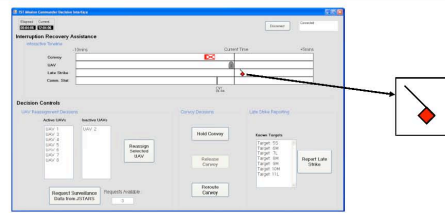


The mission commander decision display will be shown on the TabletPC you will use in the study. All of your command decisions are on this display. As mentioned earlier, the ultimate goal of the mission is to **keep the convoy safe while moving through the mission as quickly as possible**. In order to achieve this mission goal you will have three types of commands at your disposal:

1. Convoy Commands: Hold / Release position.
2. Requesting additional surveillance information from a nearby intelligence source (JSTARS) (limited usage).
3. Reassigning a UAV from one part of the AOI to another to replace a downed UAV.
4. Rerouting the convoy to the alternative path.

Mission Commander Display

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Also mentioned earlier, another part of your job as mission commander will be to monitor the strike team performance and report any unsatisfactory strike support. For the purposes of this study, unsatisfactory strike support will be defined as instances of **"late strikes"**, that is, instances of scheduled target strikes such that the strike schedule target appears to the right of its corresponding threat envelope.

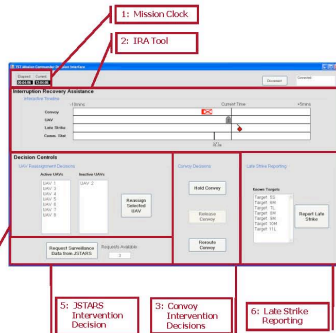
The specifics of this display and the corresponding task functionality will be explained in the following slides.

Mission Commander Display

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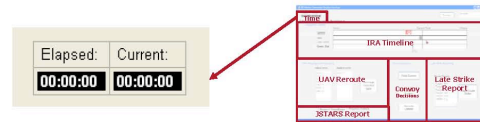
The main components of the TST mission commander decision display, described in detail next, are:

1. The mission clock.
2. Interruption Recovery Assistance (IRA) tool.
3. Convoy decisions panel.
4. UAV reassignment panel.
5. JSTARS surveillance decision panel.
6. Late Strike reporting panel.



Mission Commander Display (1) Mission Clock

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The Mission Clock shows the up-to-date mission times, including the **elapsed time** since the beginning of the test session and the **current mission time**.

This mission clock can be found in the upper right corner of all three experiment displays



Mission Commander Display (2a) IRA - Overview

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The IRA (Interruption Recovery Assistance) panel is an interactive panel consisting of a timeline and iconic bookmarks which are clickable by you. These interactive bookmarks helps you; the mission commander; quickly retain situation/activity awareness of relevant events to decision making. It is designed to be especially useful after returning from an interruption.

The timeline shown above displays the "interactive bookmarks". The timeline keeps track of four types of recent events. With the exception of "Comm. Stat" events, clicking on the icons will bring up additional information on the Map Display. After 5 seconds, this supplemental information will fade away.



Mission Commander Display (2b) IRA – Event Detection Descriptions

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The four events that will be monitored by the IRA tools are listed below.

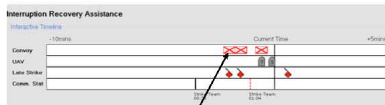
When the event occurs, the event bookmark will appear on the IRA timeline. In the first three events, if the user clicks on a bookmark, the corresponding information appears on the Map Display for 5 seconds before fading away. When Comm. Stat events occur, additional information will be presented below the timeline.

Icon	Event	Triggered By:	Select action:
	Convoy Attacked	Convoy gets attacked	Draw a red X on the spatial map (Map Display) where convoy was hit.
	UAV Destroyed	UAV is destroyed	Draw a red X over the destroyed UAV on the spatial map.
	Late Strike	A newly scheduled target strike that will not eliminate the target before the convoy passes within its weapons range.	Draw a box around the corresponding target on the strike schedule.
	Communication Status Changed	If any of the communication (JSTAR, Convoy, Strike Team) links changes status (connect/disconnect).	Display red dotted line on IRA timeline if communication was disconnected, show black, solid line if communication was reconnected. The text under the line reveals more information about the type of communication ("J" for JSTARs, Strike Schedule and CVY for Convoy) and the time it happened in the past (i.e. 00:30 means it happened 30 seconds ago).



Mission Commander Display (2c) IRA – Convoy Attacked

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Selecting a red convoy icon (see above) on the IRA timeline will reveal further detail in the Map Display. A red X (see right) indicates on the spatial map where the convoy was hit. The red X will fade after 5 seconds.

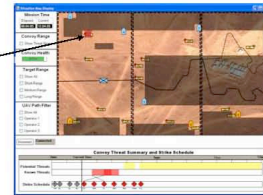


Mission Commander Display (2d) IRA – UAV Destroyed

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Selecting a gray UAV icon (see above) will reveal further detail in the Map Display. A transparent red X (see right) will be drawn on the spatial map to indicate which UAV was destroyed. The X will fade after 5 seconds.



Mission Commander Display (2e) IRA – Late Strike 45 of 51

Clicking on the late strike icon (see above) will reveal further details in the Map Display. A black box (see right) will be drawn on the Strike Schedule panel to indicate which target will become a threat before the strike team will be able to eliminate it. Also, the other targets will be dimmed to give emphasis. This box will fade after 5 seconds.

Mission Commander Display (2f) IRA – Communication Status Change 46 of 51

A solid black line indicates an event in which the communication link was restored. The label below the line indicates which connection link was down (i.e. that corresponding to JSTARS, Strike Team or Convoy), and the total length of disconnect time.

The dotted red line indicates that a communication link has gone (and is still) down. The label below the line indicates which connection is down and the current duration of the disconnect.

Mission Commander Display (3) Convoy Intervention Decisions 47 of 51

The Convoy Decisions panel enables you to:

- **Hold the convoy** – i.e., send a command to the convoy to hold its current position.
- **Release the convoy** – i.e., send a command to the convoy to resume its progress on its planned path.
- **Reassign the convoy to the alternative path** – i.e. send a command to the convoy to be rerouted to an alternative path.

NOTE: When the Convoy Communication link is disconnected, you cannot issue any of these convoy-related commands (i.e. the state of the convoy cannot be changed).

Mission Commander Display (4) JSTARS Intervention Decision 48 of 51

The JSTARS Surveillance Decision panel enables you to additional surveillance data from a nearby JSTARS (Joint Surveillance & Target Attack Radar System), a multi-sensor aircraft, within range of your team's AOI.

Requesting the JSTARS surveillance information will reveal all areas expected to be within short, medium, and long weapons range of the convoy over the next two minutes ahead of the convoy's current position.

Any identified targets will be confirmed and added to the strike schedule by the JSTARS crew. It would be appropriate to request JSTARS data, for example, if the convoy is approaching an area where the UAVs have not yet surveilled. If the revealed path is now too dangerous, the change path function can be used.

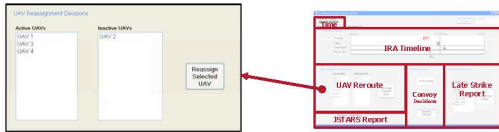
To request the JSTARS surveillance data, select the 'Request Surveillance Data from JSTARS'. A message will be received from JSTARS and the Map and Mission Status Displays will be updated accordingly.

Note, you will only be able to request JSTARS surveillance data **up to 3 times** per mission. The textbox adjacent to the 'Request Surveillance Data from JSTARS' button will display the number of remaining requests. So you should use it **sparingly**.



Mission Commander Display
(5) UAV Reassignment Intervention Decision

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The UAV Reassignment Decision panel enables you to reassign one of your team's UAV to take over the remaining surveillance route of another UAV that has been destroyed.

To reassign a UAV, select the desired UAV in the 'Active' list on the left side of the panel, then select the downed UAV from the 'Inactive' list on the right side of the panel, and finally, select the 'Reassign UAV' button. The reassigned UAV will immediately begin moving toward the downed UAV to take over its route.

Note, reassigning a UAV will cause it to **abandon** its own mission route and assume the mission route of the downed UAV. Due to limited endurance capabilities of the UAVs, once a UAV is reassigned to a new route, **it will not be able to resume its prior mission route.**

Remember that if a target attacks a UAV, **it will attack again** as long as it's not destroyed.



Mission Commander Display
(6) Late Strike Reporting Detection

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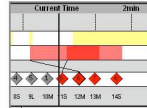


The Late Strike Reporting enables you to report any late strikes in the strike schedule, corresponding to unsatisfactory strike support.

A **late strike** is an instance when a strike is scheduled after a known threat envelope is beginning. A late strike can be determined from the threat summary & strike schedule timeline on both large screen displays. For example, target 12M in the displayed timeline is an example of a **late strike**: 11S is not a late strike because it will be destroyed before the convoy will be within its weapons range.

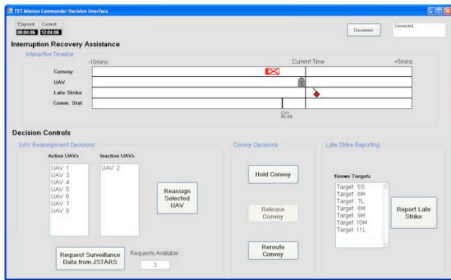
You are expected to report as many instances of late strikes as possible. To do so, select the respective target from the 'Known Targets' and then selecting the 'Report Late Strike' button.

Threat Summary & Strike Schedule



Any Questions?

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Advance slide when you are ready...



Begin Practice Sessions

52

Mission Priorities	Tools you can use to keep the convoy safe
high priority: <ol style="list-style-type: none"> 1. Move the convoy through your AOI as quickly as possible 2. Keep the convoy safe 	<ul style="list-style-type: none"> - Hold, Release Convoy - Lose health when convoy held - Are you currently in the range of target(s)?
Lower priority: <ol style="list-style-type: none"> 1. Assist the remote operators in your team in completing the assigned set of target designations 2. Report late strikes 3. Survey all roads in your AOI 	<ul style="list-style-type: none"> - Reroute Convoy (Moving backwards if you are past the intersection) - JSTARs to reveal unsurveilled area (3 times) - Reroute UAVs to complete dead UAV's path and continue to surveil the convoy's path - Helping your team members via Remote Operator Assistance Display <ul style="list-style-type: none"> - Are the UAVs taking too long to identify targets?

Appendix F

The Post-tutorial Script

The post-tutorial script below will be used to ensure all participants were told the same major points and the same subtleties were addressed.

- 1) Mission objectives: Primary (Stress the time-criticality of the mission), Secondary objectives
- 2) Lose health for Convoy attacked and holding.
- 3) Interruptions may occur at any time, will be told how long the interruption will be, have 5 seconds to vacate the room.
- 4) Map Display (highlight the following):
 - Filters
 - UAVs fly to the corner at the end but they are still active
 - Threat envelopes, potential threat (explain how can get hit if you are in the yellow but not red region), late strike
 - Convoy doesn't get attacked until center inside the convoy gets into a target range, use red envelopes
- 5) Mission Status Summary (highlight the following):
 - UAV status (idle for >30 seconds, then click request)
 - Operator performance
 - Communication status (JSTAR)
- 6) Mission Commander Interface (highlight the following):

- Hold/Release Convoy (Convoy Communication Link)
- Reassign UAV only once and make sure the target is **NOT** active (try to do it sooner than later)
- Late Strike Report
- IRA how to use

7) Remote Assistance Display (highlight the following)

- Requesting details
- Target Classification (Stress they are almost always correct)

Appendix G

Post-experimental Interview

This is a list of the interview questions that will be asked after the completion of the experimental trail. This list of questions aims to gain a qualitative understanding of the participant's experience during the mission.

1. Which interface did you find most helpful for the mission?
2. Did you find the mission task challenging?
3. Did you find the interruption task distracting enough to take your mind off the mission? Did you find it long enough?
4. Did you ever use the IRA tool? If yes, did you only use it after the interruptions?
5. To expand on your use of the IRA tool, did you use it for mission replay? If yes, when? If no, why not?
6. Did you ever use the IRA event timeline just to gather mission information? If yes, when, and what did you find the most helpful?
7. Now I'm going to walk you through the interruptions in your last scenario. For each interruption, I'll show you on the video replay the mission status when you returned from the interruption. Can you please explain:
 - how you determined what changes in the scenarios had occurred?
 - what changes you identified?
 - what decision you made to address those changes?
8. Do you have any other comments or suggestions about the usability of the interfaces or the mission task?

Appendix H

Interruption Tasks

The links to the scenarios used are as follows:

<http://www.placespotting.com/solve.php?placeId=74C-489A3B70-B73>

<http://www.placespotting.com/solve.php?placeId=3EF-488FB174-1D33>

<http://www.placespotting.com/solve.php?placeId=1BCC-488FB4D4-1078>

<http://www.placespotting.com/solve.php?placeId=FFA-489B39DD-23A2>

<http://www.placespotting.com/solve.php?placeId=18C2-489B3BBE-864>

Find the place on this map...

Imagery ©2009 DigitalGlobe, GeoEye - Terms of Use

ID of the map quiz: 1BCC-488FB4D4-1078
Creation date of the quiz: 2008-07-30 02:24:52
Times it was solved before: 63
Map zoom level: 18

Some Hints for your Help:

- Iraq
- Baghdad

[Click here to send this map quiz to a friend.](#)
[Click here to try another map quiz.](#)

Rate this quiz:
☆☆☆☆

Your solution... Drag/zoom the lower map. Zoom must match exactly, latitude/longitude approximately.

Map Satellite Hybrid

OWN THE WORLD!
Buy your favorite place and make it famous
[Click here to learn more](#)

WYP
Where your place is

NOT SOLVED

Latitude: 38 Longitude: -23.5 Zoom: 2

Figure 23. Sample interruption task used for the user studies

Appendix I

Test Statistics for Study 1

Anova Table

Score Statistics For Type 3 GEE Analysis

Source	DF	Chi-	
		Square	Pr > ChiSq
assistance	1	10.62	0.0011
decision	1	5.34	0.0209
assistance*decision	1	0.08	0.7727
exp	1	2.08	0.1495

Contrast Estimate Results

Label	Standard		Alpha	Chi-		Square	Pr > ChiSq
	Estimate	Error		Confidence Limits	Square		
IRA vs NoIRA	2.0984	0.5098	0.05	1.0992	3.0977	16.94	<.0001
Exp(IRA vs NoIRA)	8.1534	4.1567	0.05	3.0018	22.1459		
Simple vs com	1.6379	0.6946	0.05	0.2765	2.9993	5.56	0.0184
Exp(Simple vs com)	5.1445	3.5734	0.05	1.3185	20.0719		

Results of McNemar's test for a case-control study

Summary:

If there were no association between the risk factor and the disease, you'd expect the number of pairs where cases was exposed to the risk factor but control was not to equal the number of pairs where the control was exposed to the risk factor but the case did not. In this study, there were 6 discordant pairs (case and control had different exposure to the risk factor). There were 6 (100.000%) pairs where the control was exposed to the risk factor but the case was not, and 0 (0.000%) pairs where the case was exposed to the risk factor but the control was not.

P Value:

The two-tailed P value equals 0.0412
By conventional criteria, this difference is considered to be statistically significant.

The P value was calculated with McNemar's test with the continuity correction.
Chi squared equals 4.167 with 1 degrees of freedom.

The P value answers this question: If there is no association between risk factor and disease, what is the probability of observing such a large discrepancy (or larger) between the number of the two kinds of discordant pairs? A small P value is evidence that there is an association between risk factor and disease.

Odds ratio:

The odds ratio is 0.000, with a 95% confidence interval

Review your data:

		Control		Total
		+	-	
Case	+	17	6	23
	-	0	1	1
Total		17	7	24

Results of McNemar's test for a case-control study

Summary:

If there were no association between the risk factor and the disease, you'd expect the number of pairs where cases was exposed to the risk factor but control was not to equal the number of pairs where the control was exposed to the risk factor but the case did not. In this study, there were 14 discordant pairs (case and control had different exposure to the risk factor). There were 2 (14.286%) pairs where the control was exposed to the risk factor but the case was not, and 12 (85.714%) pairs where the case was exposed to the risk factor but the control was not.

P Value:

The two-tailed P value equals 0.0162

By conventional criteria, this difference is considered to be statistically significant.

The P value was calculated with McNemar's test with the continuity correction.

Chi squared equals 5.786 with 1 degrees of freedom.

The P value answers this question: If there is no association between risk factor and disease, what is the probability of observing such a large discrepancy (or larger) between the number of the two kinds of discordant pairs? A small P value is evidence that there is an association between risk factor and disease.

Odds ratio:

The odds ratio is 0.167, with a 95% confidence interval extending from 0.018 to 0.749

Review your data:

		Control		
		+	-	Total
Case	+	7	2	9
	-	12	3	15
Total		19	5	24

Appendix J

Learning Effect Test

For each participant, the average of the recovery time in assistance conditions and no assistance conditions across decision types was calculated, and this average was used as the response for the ANOVA test. The ANOVA result showed no overall order effect, that is the average over the assistance condition (AT1) and no assistance condition (AT2) for different orders (i.e. Order 1 was to have the assistance in the first trial and Order 2 was to have the assistance in the second trial) was not significantly different. In addition, the interaction between assistance type (AT) and assistance order, was not significant ($p = .58$). Thus the difference between the average AT1 and AT2 within Order 1 is not significantly different than the difference between average AT1 and AT2 within Order 2. Therefore, we can conclude that there was no learning effect and the effect of assistance type was not confounded by the order by which the trials were run.

Appendix K

Test Statistics for Study 2

ANOVA Table:

Tests of Between-Subjects Effects

Dependent Variable: LogTransform

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	272.709	1	272.709	418.935	.000
	Error	8.462	13	.651 ^a		
IntMob	Hypothesis	.521	1	.521	.768	.386
	Error	26.469	39	.679 ^b		
DecType	Hypothesis	2.564	1	2.564	3.778	.059
	Error	26.469	39	.679 ^b		
IntMob * DecType	Hypothesis	6.419	1	6.419	9.457	.004
	Error	26.469	39	.679 ^b		
Subject	Hypothesis	8.462	13	.651	.959	.506
	Error	26.469	39	.679 ^b		

a. MS(Subject)

b. MS(Error)

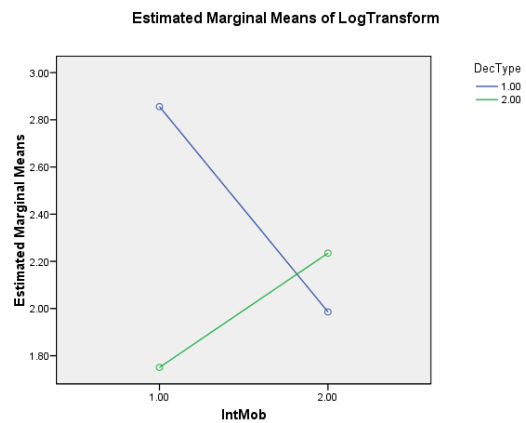
The two factors should be over MSAB instead of MSE for the F statistic as SPSS calculates them.

The new F values and P values are:

- $F_{AT}=0.0812$, $p=0.7769$
- $F_{DD}=0.399$, $p=0.5304$

Significant Interaction:

Main Effects plots:



Pearson correlations of cell data:

Correlations

		Simplnt	SimpMob	Complnt	CompMob
Simplnt	Pearson Correlation	1	-.435	.297	.408
	Sig. (2-tailed)		.120	.303	.147
	N	14	14	14	14
SimpMob	Pearson Correlation	-.435	1	-.327	-.133
	Sig. (2-tailed)	.120		.254	.650
	N	14	14	14	14
Complnt	Pearson Correlation	.297	-.327	1	.070
	Sig. (2-tailed)	.303	.254		.811
	N	14	14	14	14
CompMob	Pearson Correlation	.408	-.133	.070	1
	Sig. (2-tailed)	.147	.650	.811	
	N	14	14	14	14

McNemar Contingency Table for Complex Situations:

Complex Decision: Integrated	Mobile		
	Correct	Incorrect	Total
Correct	5	6	11
Incorrect	2	1	3
Total	7	7	14

Appendix L

Study 2 Detailed Analysis

Since both main effects were not significant, it is less important, but it warrants investigation to ensure that there is not something skewing the data, especially based on the main effects plots and previous experimental data on the effectiveness of the tool. Initially this would suggest that there are multicollinearity problems since the interaction is so significant, but as discussed earlier this does not seem to be the case. No significance and fewer subjects than recommended also means a lower observed power will be observed for each of these tests. Table 1 shows the observed power values after the fact for each of the factors and also for the interaction. The high power value for the interaction term makes sense here because of the high significance of that term in the model.

Table 4: Observed power values for each experimental factor

Factor	Observed Power
Assistance Type	0.137
Decision Difficulty	0.474
Subject	0.471
Assistance Type*Decision Difficulty	0.851

Since neither of the two factors were significant it was meaningless to perform post hoc pairwise comparisons, but given the main effects plot showing the interaction below (Figure

24: Main effects plot showing contrast comparisons) it made sense to also examine the interaction term by doing a couple of contrast comparisons.

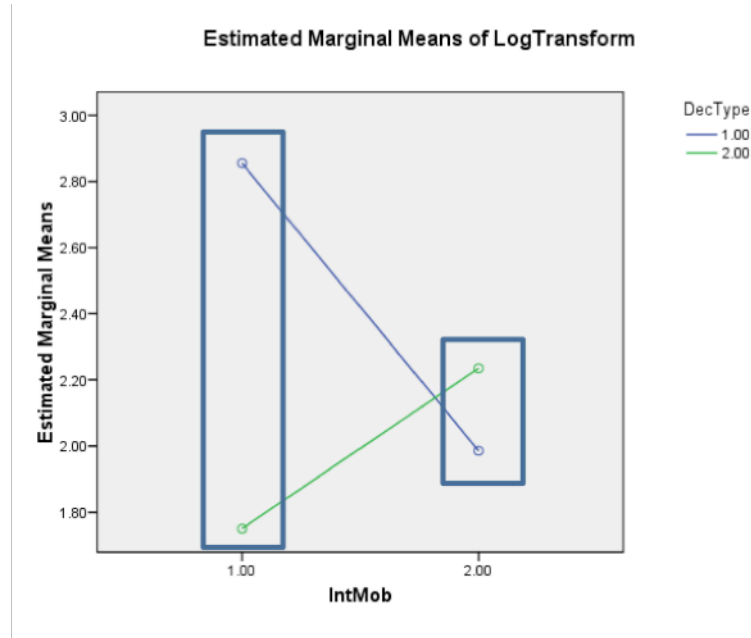


Figure 24: Main effects plot showing contrast comparisons

Those two contrasts were calculated according to the following formulas:

$$L_1 = \mu_{11} - \mu_{12}$$

$$L_2 = \mu_{21} - \mu_{22}$$

Where:

$$\mu_{11} = \mu_{11} - \mu_{12} \quad \mu_{21} = \mu_{21} - \mu_{22}$$

Those two contrasts, L_1 and L_2 both came out significant, however the case for assistance type 2 (along the x axis), was only marginally significant with $t^* = 2.65$ and t -critical $(0.975, 52) = 2.308$. For the first assistance type condition (Integrated display), $t^* = 20.48$, a far greater test statistic, which indicates a large difference in these two cell means, which we would expect based on the figure.

Bibliography

- Adamczyk P. D. & Bailey B. P. (2004) If not now, when?: The effects of interruption at different moments within task execution, in: *Human Factors in Computing Systems: Proceedings of CHI'04*, New York: ACM Press, 271-278
- Adamczyk P. D., Iqbal S. T. & Bailey B. P. (2005) A method, system, and tools for intelligent interruption management, in: *Proceedings of the 4th International Workshop on Task Models and Diagrams (TAMODIA'05)*, New York: ACM Press, 123-126
- Bailey B. P., Adamczyk P. D., Chang T. Y. & Chilson N. A. (2006) A framework for specifying and monitoring user tasks, *Computers in Human Behavior*, 22 (4), 709-732
- Bailey B. P. & Konstan J. A. (2006) On the need for attention-aware systems: Measuring effects of interruption on task performance, error rate, and affective state, *Computers in Human Behavior*, 22 (4), 685-708
- Cooke, N.J. & Gorman, J.C. (2006). Assessment of team cognition. In P. Karwowski (Ed.), 2nd EDITION- *International Encyclopedia of Ergonomics and Human Factors* (pp. 270-275). UK: Taylor & Francis Ltd.
- Cooke, N. J., Gorman, J., Pedersen, H., & Bell, B. (2007). Distributed Mission Environments: Effects of Geographic Dispersion on Team Cognition and Performance. S. Fiore and E. Salas (Eds.), *Toward a science of distributed learning* (pp. 147-167). Washington, DC: American Psychological Association.
- Dabbish L. & Kraut R. (2004) Controlling interruptions: Awareness displays and social motivation for coordination, in: *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW'04)*, New York: ACM Press, 182-191
- Fogarty J., Hudson S. E., Atkeson C. G., Avrahami D., Forlizzi J., Kiesler S., Lee J. C. & Yang J. (2005) Predicting human interruptibility with sensors, *ACM Transactions on Computer-Human Interaction*, 12 (1), 119-146
- Hughes, J. A., Randall, D. and Shapiro, D. (1992). Faltering from ethnography to design. In ACM (Ed.), *Proceedings of CSCW'92 Computer-Supported Cooperative Work*. Toronto, Canada.

- Law A. S., Logie R. H., Pearson D. G., Cantagallo A., Moretti E. & Dimarco F. (2004) Resistance to the impact of interruptions during multitasking by healthy adults and dysexecutive patients, *Acta Psychologica*, 116 (3), 285-307
- McCrickard D. S., Chewar C. M., Somervell J. P. & Ndiwalana A. (2003) A model for notification systems evaluation - Assessing user goals for multitasking activity, *ACM Transactions on Computer-Human Interaction*, 10 (4), 312-338
- McFarlane D. C. (1998) *Interruption of People in Human-Computer Interaction*, Doctoral Dissertation, George Washington University, Washington
- McFarlane D. C. (2002) Comparison of four primary methods for coordinating the interruption of people in human-computer interaction, *Human-Computer Interaction*, 17 (1), 63-139
- McFarlane D. C. & Latorella K. A. (2002) The scope and importance of human interruption in human-computer interaction design, *Human-Computer Interaction*, 17 (1), 1-61
- Monk C. A., Boehm-Davis D. A. & Trafton J. G. (2004) Recovering from interruptions: Implications for driver distraction research, *Human Factors*, 46 (4), 650-663
- National Transportation Safety Board. (1988). Aircraft accident report, Northwest Airlines Inc., McDonnell-Douglas DC-9-82, N312RC, Detroit Metropolitan Wayne County Airport, Romulus, Michigan (NTSB-AAR-88-05). Washington, DC: National Transportation Safety Board.
- Oulasvirta A. & Saariluoma P. (2006) Surviving task interruptions: Investigating the implications of long-term working memory theory, *International Journal of Human-Computer Studies*, 64 (10), 941-961
- Patterson E. S., Watts-Perotti J. & Woods D. D. (1999) Voice loops as coordination aids in space shuttle mission control, *Computer Supported Cooperative Work (CSCW)*, 8 (4), 353-371
- Russell E., Purvis L. M. & Banks A. (2007) Describing the strategies used for dealing with email interruptions according to different situational parameters, *Computers in Human Behavior*, 23 (4), 1820-1837
- Scott, S.D., Mercier, S., Cummings, M.L., Wang, E. (2006). Assisting Interruption Recovery in Supervisory Control of Multiple UAVs. In *Proceedings of HFES 2006: 50th Annual Meeting of the Human Factors and Ergonomic Society*, October 16-20, 2006, San Francisco, CA, USA.

- Scott, S.D. & Cummings, M.L. (2006). Aiding Team Supervision in Collaborative Time-Sensitive Targeting: Design of Experiment. Technical Report HAL2006-05, Humans and Automation Laboratory, Massachusetts Institute of Technology, Cambridge, MA, July 2006.
- Sen, S., Geyer, W., Muller, M, Moore, M., Brownholtz, B., Wilcox, E. & Millen, D.R. (2006) FeedMe: A Collaborative Alert Filtering System, *Computer Supported Cooperative Work, Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*. November 4-8, 89-98.
- Speier, C., Valacich, J.S., & Vessey, I. (1997). The effects of task interruption and information presentation on individual decision making. Proceedings of the Eighteen International Conference on Information Systems, 21-36
- St. John M., Smallman H. S. & Manes D. I. (2005) Recovery from interruptions to a dynamic monitoring task: The beguiling utility of Instant Replay, in: *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting (HFES'05)*, Santa Monica: Human Factors and Ergonomics Society, 473-477
- Trafton J. G., Altmann E. M. & Brock D. P. (2005) Huh, what was I doing? How people use environmental cues after an interruption, in: *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting (HFES'05)*, Santa Monica: Human Factors and Ergonomics Society, 468-472
- Trafton J. G., Altmann E. M., Brock D. P. & Mintz F. E. (2003) Preparing to resume an interrupted task: Effects of prospective goal encoding and retrospective rehearsal, *International Journal of Human-Computer Studies*, 58 (5), 583-603
- Van Bergen, A. (1968). *Task Interruption*. Amsterdam: North-Holland Publishing Company
- Wan, J., Scott, S.D. and Cummings, M.L. (2007). Assisting Interruption Recovery in Mission Control Operations. HAL2007-03, Humans and Automation Laboratory, Massachusetts Institute of Technology.
- Wickens C. D., Dixon S. R. & Seppelt B. (2005) Auditory preemption versus multiple resources: Who wins in interruption management?, in: *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting (HFES'05)*, Santa Monica: Human Factors and Ergonomics Society, 463-467