Assisting Interruption Recovery in Mission Control Operations

by

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Assisting Interruption Recovery in Time Sensitive Targeting Mission Control Operations

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Frequent interruptions are commonplace in modern work environments. The negative impacts of interruptions are well documented and include increased task completion and error rates in individual task activities, as well as interference with team coordination in team-based activities. The ramifications of an interruption in mission control operations, such as military command and control and emergency response, can be particularly costly due to the time and life-critical nature of these operations. The negative impacts of interruptions have motivated recent developments in software tools, called interruption recovery tools, which help mitigate the effects of interruptions in a variety of task environments. However, mission control operations introduce particular challenges for the design of these tools due to the dynamic and highly collaborative nature of these environments.

To address this issue, this thesis investigates methods of reducing the negative consequences of interruptions in complex, mission control operations. In particular, this thesis focuses on supporting interruption recovery for team supervisors in these environments, as the research has shown that supervisors are particularly susceptible to frequent interruptions. Based on the results of a requirements analysis, which involved a cognitive task analysis of a representative mission control task scenario, a new interruption recovery tool, named the Interruption Recovery Assistance (IRA) tool, was developed. In particular, the IRA tool was designed to support a military mission commander overseeing a team of unmanned aerial vehicle (UAV) operators performing ground force protection operations. The IRA tool provides the mission commander a visual summary of mission changes, in the form of an event bookmark timeline. It also provides interactive capabilities to enable the commander to view additional information on the primary task displays when further detail about a particular mission event is needed.

The thesis also presents the findings from a user study that was conducted to evaluate the effectiveness of the IRA tool on interruption recovery during collaborative

UAV mission operations. The study produced mixed results regarding the effectiveness of the IRA tool. The statistical analysis indicated a negative impact on recovery time, while indicating a positive impact on decision accuracy, especially in complex task situations. The study also indicated that the effect of the IRA tool varied across differ user populations. In particular, the IRA tool tended to provide greater benefits to participants without military experience, compared to military participants involved in the study. The qualitative findings from the study provided key insights into the impact and utility of the IRA tool. These insights were used to identify several future research and design directions related to interruption recovery in mission control operations.

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Nomenclature

Acronyms

AOI	Area of Interest
CEO	Chief Executive Officer
DL	Decision Ladder
HSC	Human Supervisory Control
IAI	Interruption Assistance Interface
IR	Interruption Recovery
IRA	Interruption Recovery Assistance
IRT	Interruption Recovery Time
JSTARS	Joint surveillance and target attack radar system
mCDR	Mission Commander
MCI	Mission Commander Interface (tablet PC)
MSD	Mission Status Display
MD	Map Display
RAD	Remote Assistance Display
SS	Simulation Server
UAV	Unmanned Aerial Vehicle

Chapter 1: Introduction

In modern work environments, people are regularly bombarded with interruptions. These interruptions often stem from people's computers, for example, from instant messaging programs, email clients, and scheduled computer maintenance tasks. Interruptions also occur from non-computer-based sources, such as telephone calls and co-workers stopping by for assistance.

Research has shown that such interruptions can have a variety of negative consequences. For example, interruptions can increase job stress, task completion times, and error rates in individual task activities (Kirmeyer 1988; Cellier and Eyrolle 1992; Czerwinski, Cutrell et al. 2000; Czerwinski, Cutrell et al. 2000). Empirical studies have shown that, in general, interruptions can negatively impact overall task performance (Monk, Boehm-Davis et al. 2002; Trafton, Altmann et al. 2003; Altmann and Trafton 2004). Research has also shown that interruptions can also cause coordination problems, work overload, and time pressure in team-based activities (Reder and Schwab 1990; Jett and George 2003). Depending on the criticality of the task being performed, the ramifications of interruptions can vary from being mildly annoying or socially embarrassing to potentially leading to loss of equipment or life (Bailey, Konstan et al. 2000; Tucker and Spear 2006).

In team oriented work environments, collaboration requires multiple interactions among co-workers and their supervisors. With the addition of instant messaging and other forms of collaboration technologies, it has become increasingly easy to interrupt someone, even from a distance. Team supervisors are particularly susceptible to interruptions in the work place (Jett and George 2003). In a study by Oshagbemi (1995), it was found that significant improvements in the use of a supervisor's time can be obtained by addressing workplace interruptions and their negative impacts through delegation, rescheduling and minimizing the frequency of interruptions.

In some cases, the negative consequences of interruptions can be mitigated through rescheduling using a computer mediator or social negotiation mechanisms (McFarlane and Latorella 2002; Dabbish and Kraut 2004). In these situations, the flexibility of the task environment can allow the user to determine when they want to be interrupted and thereby reduce the cost of an interruption.

While interruptions can be a negative source of distraction, they are often the source of critical and highly relevant information. For example in medical or military task environments, interruptions often take the form of colleagues relaying urgent information that has direct impact on someone's current decision making activities (Tucker and Spear 2006). When the importance of receiving current information updates is likely to outweigh the potential negative effects of an interruption, it may not be appropriate to reschedule or negotiate when interruptions will occur.

The primary goal of this thesis is to investigate alternative methods of reducing the negative consequences of interruptions in complex, time-critical task environments in which the timing of the interruptions cannot be controlled. In particular, this thesis focuses on methods of minimizing the impact of interruptions on team supervisors in such time-critical environments, as research has shown that they tend to be the most vulnerable to interruptions in collaborative environments (Oshagbemi 1995; Jett and George 2003).

1.1 Motivation

Mitigation of the negative effects of interruptions on computer-based tasks through computer facilitation is known as interruption recovery and concerns the process of transitioning from an interruption back to the original task. Depending on the type of interruption, the recovery period can be a lengthy process. The duration of the interruption recovery process is contingent on the time needed for a person to recall where they were in the task and what activities are required before they can effectively continue the task. Thus, the challenge of a computer-based interruption recovery assistance tool is to help minimize the time and mental effort needed to resume a person's original task. This section will discuss the fundamental research of interruptions and team supervision as to create the foundation for the research domain of this thesis.

1.1.1 Interruptions

Corragio (1990) defines an interruption as an "externally-generated, randomly occurring, discrete event that breaks continuity of cognitive focus on a primary task". From this definition, it can be deduced that an interruption is an external distraction (by someone or something other than the person being distracted), that is beyond the control of the individual being interrupted.

Cognitively, an interruption interferes with memory capacity and diverts the decision maker's attention away from the primary task (Kahneman 1973). This interference typically leads to disruptions in ongoing thought processes (Tetard 1999), likely contributing to the delays often observed in post-interruption task resumption. Such delays are referred to as reorientation time (Gillie and Broadbent 1989), resumption lag (Altmann and Trafton 2004), or interruption recovery time (Scott, Mercier et al. 2006), and are discussed further in Chapter 2. Research also indicates that erratic disruptions can induce personal stress that can negatively affect post-interruption performance (Cohen 1980).

In certain work environments, the introduction of interruptions actually improves performance (Speier, Valacich et al. 1997). Specifically, Speier et al. (1997) found that when tasks are simple, human operators tend to occupy their unused cognitive capacity with non-task-related activities. Thus, being interrupted actually requires them to focus more deeply on the primary task, resulting in better overall performance. However, Speier et al.'s research also found that when people are involved in complex or cognitively demanding tasks, interruptions can decrease their performance. The decrease in performance can be attributed to the nature of complex tasks requiring parallel processing of multiple sources of information. Interruptions that occur in complex environments generate an additional thread of a parallel cognitive process, which can interfere with original task's processes (Tetard 2000).

Another facet of why interruptions are such a prominent issue in modern work environments is that people have a natural tendency to multitask (Cherry 1953; Cypher 1986; Woods. 1995). Multitasking is a skill set that is unreliable and vulnerable to other events that can cause human mistakes (McFarlane and Latorella 2002). In some work environments, a certain number of mistakes may be acceptable and have little impact on overall task performance. However, in time- or life-critical task environments, such as emergency response or military operations, the consequences can be extremely detrimental. Therefore, it is important to consider the environment in which interruptions occur. The following section will discuss team environments, and how interruptions can interfere with collaboration.

1.1.2 Team Supervision

With advances in technology and the globalization of economies, the organizational structures of work environments are becoming more dynamic (Brown and Eisenhardt 1998) and team-oriented (Gordon 1992; Devine, Clayton et al. 1999). Naturally, collaboration and leadership from team leaders are central to the success of many team environments, especially in large organizations. Team supervisors are usually responsible for the success of the entire team, and thus they must monitor the performance and assist their subordinates when necessary. As mentioned earlier, team supervisors are particularly susceptible to negative impacts from interruptions. One study has shown that supervisors fail to return to their prior activities almost 50% of the time following an interruption (O'Conaill and Frohlich 1995). The disruptiveness of interruptions on team supervision is compounded by the fact that an interrupter tends to gain more from the exchange than an interrupted person (O'Conaill and Frohlich 1995). Over time, this unequal benefit tends to disadvantage the team supervisor, leaving them little time to complete their own work duties (Jett and George 2003).

A detailed assessment of how managers spend their time reveals some interesting trends. Traditionally, the role of a team supervisor is to plan, organize, lead, coordinate and control (Fayol 1949). However, a more recent studies of team supervisors have found that supervisors spend the majority of their long work days (on average, 10 hours per day) in scheduled and emergency meetings, on the phone, or having spontaneous communications in order to request or provide assistance (Reder and Schwab 1990; Oshagbemi 1995). Team supervisors also tend to have more emergency meetings than scheduled ones, though the time spent in scheduled meetings is usually longer (Oshagbemi 1995).

Senior supervisors, such as Chief Executive Officers (CEOs), can experience interruptions at alarmingly frequent rates, including every eight to 22 minutes (Carlson 1951; Mintzberg 1973). Arguably, the frequency of interruptions will fluctuate within different work domains and specific work populations. However, it is certain that frequent interruptions can force team supervisors to think through important issues in extremely short blocks of time (Sproull 1984; Reder and Schwab 1990). As supervisory-level decision making and task activities ultimately impacts overall team performance, minimizing the disruptiveness of the interruptions supervisors encounter could improve their productivity, but also the productivity of the entire team.

The challenges of team supervision are not limited to just having to deal with interruptions from subordinates and coworkers. The interactions that occur in today's complex environments are no longer purely human-human. The next section will consider the effects of interruptions in task domains that involve human interaction with intelligent computer systems.

1.2 Research Objectives

In order to address the issues raised in the previous section, the overarching goal of this research is to develop an interruption recovery assistance tool for team supervisors in a complex, collaborative human supervisory control task environment. This goal will be addressed through the following research objectives:

- Objective 1: **Determine the interruption recovery requirements for team supervisors in a complex human supervisory control team environment.** In order to achieve this objective, a literature review and a cognitive task analysis were conducted to identify interruption requirements for a representative complex, collaborative human supervisory task. The results of this requirements analysis are detailed in Chapter 3.

- Objective 2: **Develop an interruption recovery tool for a representative complex human supervisory control team environment.** Based on the requirements analysis, an interruption recovery assistance tool was designed. The design goals for this tool and its integration into an existing experimental task environment are discussed in Chapter 3.

- Objective 3: **Evaluate the effectiveness of the new interruption recovery tool for team supervisors in a complex human supervisory control team environment.** To achieve this objective, a user study was conducted to evaluate the proposed design of the interruption recovery assistance tool. The complete description of the study and its results can be found in Chapters 4 and 5.

1.3 Thesis Overview

This thesis is organized into the following chapters:

- Chapter 1, *Introduction*, introduces and describes the motivation and research objectives of this thesis.

- Chapter 2, *Background and Related Work*, provides a summary of prior research related to interruption recovery and the current technological state of interruption recovery assistance tools in the human supervisory control domain.

- Chapter 3, *Interruption Recovery Assistance Tool*, describes the interruption recovery requirements analysis, the resulting design of a new interruption recovery assistance tool, and the representative complex, collaborative human supervisory control task environment upon which the requirements analysis and the proposed interruption recovery assistance tool are based.

- Chapter 4, *Evaluation Methodology*, presents a user study that was conducted to evaluate the effectiveness of the interruption recovery assistance tool described in Chapter 3. Details about the objectives, participants, and procedures utilized in the experiment are outlined.

- Chapter 5, *Results and Discussion,* discusses the statistical and qualitative results of the experiment described in Chapter 4. Implications of these results for the design of future interruption recovery assistance tools for time-critical environment are discussed.

- Chapter 6, *Conclusions,* summarizes the motivation and objectives of this research, how well the objectives were met, and the key contributions. Suggestions for future work are also provided.

Chapter 2: Background and Related Work

This chapter provides an overview of the previous research that has been done on interruption recovery. Research in the field of interruption recovery has generally focused on three main areas: investigating the effects of interruptions (Monk, Boehm-Davis et al. 2002; Speier, Vessey et al. 2003; Trafton, Altmann et al. 2003; Altmann and Trafton 2004), developing strategies for managing interruptions, including intelligent alerting and notification of computer-initiated interruptions (McFarlane and Latorella 2002; Dismukes 2003; Chen and Vertegaal 2004; Trafton, Altmann et al. 2005), and developing tools and strategies that minimize the negative impacts of interruptions (Daniels, Regli et al. 2002; St. John, Smallman et al. 2005; Scott, Mercier et al. 2006). This thesis is concerned with the latter research direction: developing decision aids to mitigate interruptions. This chapter provides an overview of the related work in this area. First, the interruption recovery research in typical computing environments is discussed, followed by relevant research on interruption recovery in human supervisory control environments, especially for complex collaborative task environments.

2.1 Interruption Recovery

Interruption recovery research generally focuses on developing tools that attempt to decrease the "resumption lag" that occurs after an interruption has occurred. Resumption lag, also known as reorientation time (Gillie and Broadbent 1989) or interruption recovery time (Scott, Mercier et al. 2006), is the "time between leaving the secondary task and beginning the primary task after an interruption" (Trafton, Altmann et al. 2005). Figure 1 shows the timeline of a typical interruption and task resumption process.

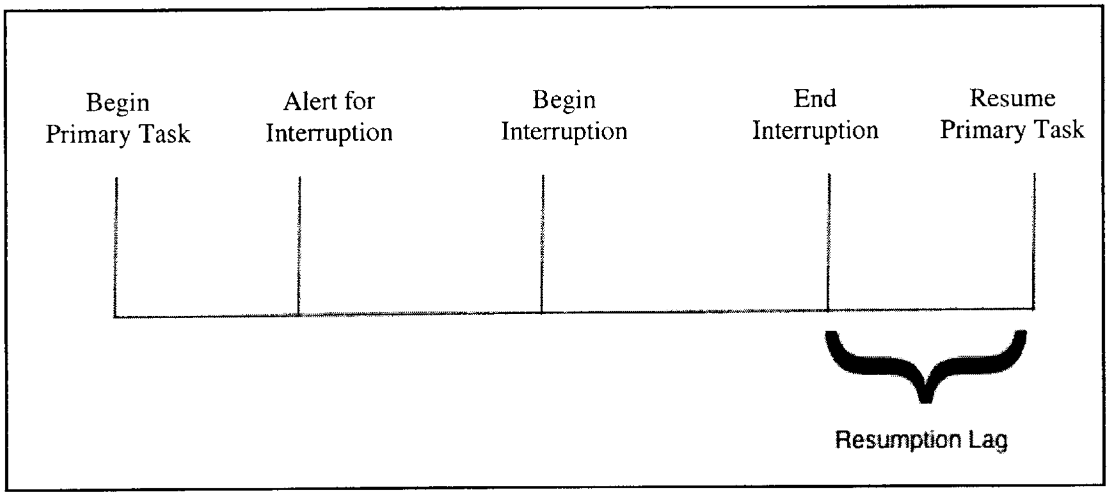


Figure 1. Interruption & recovery process (St. John, Smallman et al. 2005; Trafton, Altmann et al. 2005).

One approach to minimizing a user's interruption recovery time is to provide support within the primary task interface to help the user recall what they were doing before the interruption (Altmann and Trafton 2004). In Altmann and Trafton's study, they investigated the effects of external cues on the resumption lag. They found that when participants were given cues in the form of an eyeball image indicating an interruption was about to occur and a mouse cursor being placed at where they left off after returning from an interruption, their resumption lag was substantially shorter than those who were not given any cues. This implies that the availability of the cues prepared the mental process of the participant to help mitigate the negative effects of the interruption.

In human supervisory control (HSC) domains, in which one or more human operators are responsible for monitoring complex control processes, the task environment, including computer information displays, can dynamically change without direct input from the human operator. Thus, interruption recovery in these task domains depends heavily on understanding any events that occur while a person is distracted by an interruption. The next section discusses an important design challenge for supporting interruption recovery in HSC domains and approaches that have been proposed to address this challenge.

2.2 Change Blindness

Change blindness occurs when large changes within a visual scene go undetected by the viewer. The concept of "change blindness" in interfaces is a well documented problem in many task domains (Rensink 2002; DiVita, Obermayer et al. 2004). Research indicates that people can fail to notice large changes in a visual display especially after looking away from the screen during an interruption (Rensink, O'Regan et al. 1997; Durlach 2004). Specifically, a study by Simon and Ambinder (2005) found that change blindness occurs whenever attention is diverted from the original task. Moreover, they also found that consciously trying to focus one's attention by itself is insufficient for change detection on visual interfaces. However, change blindness has only recently been recognized as a significant challenge in human computer interactions (Smallman 2002; Smallman and St. John 2003; Durlach 2004; Varakin, Levin et al. 2004).

Change blindness is particularly relevant to HSC task environments because of the high frequency of dynamically changing data. In static environments, the information will not be updated (such as word processors, calculators, etc.), and therefore the user does not need to be concerned with observing any changes while they are gone for an interruption. However, in HSC task domains where data is dynamically changing, system changes can occur on a user's computer display while they are attending to an interruption, and change blindness could prevent them from observing these changes. The following sections will describe several approaches that attempt to assist human operators in HSC task environments recover from interruptions, and in particular, provide strategies to mitigate the effects of change blindness in these environments.

2.3 Logging of Key Events

One approach to assist interruption recovery in HSC task environments is to include a basic text log in the user interface (Malin, Schreckenghost et al. 1991; St. John, Smallman et al. 2005; Scott, Mercier et al. 2006). Specifically, a text log is an integrated display that generates ASCII characters in the forms of messages or description boxes. Messages are particularly useful in alerting a user about the occurrence of an event, especially when combined with a time stamp or recorded in an event log.

Malin et al. (1991), for example, provided users of the DESSY (DEcision Support SYstem) a simple text log that kept track of recent events that were relevant to decision making. DESSY is a decision support system used at NASA for space station operators who monitor telemetry data of space shuttles and makes inferences about commands, state transitions, and system failures. In their recovery tool, the description boxes were used to display updated values of state information, such as health and telemetry. This information could be then used to make decisions about mechanical operations of the space shuttle or monitor the health of the hardware on the shuttle.

2.4 Verbal Queries

Most interruption recovery research has focused on mitigating the negative effects of interruptions through the development of visual interfaces (e.g., Smallman and St. John 2003; Altmann and Trafton 2004; St. John, Smallman et al. 2005). An alternative is to enable users, through verbal queries, to actively control what information they want the system to provide them about its current state and past events. Daniels et al. (2002) developed an interruption recovery tool that uses a spoken dialogue interface to help someone recover from disruptions while tracking logistics requests on behalf of forward deployed ground troops. The interface provides the user with verbal commands that allows them to query the interface about aspects of the previous task. Some of the possible queries were "Where was I?" and "What was I last working on?" In addition, the user can ask specific questions relevant to the task they were working on.

This approach may provide more flexibility and control to the user, since it enables them to use the visual channel for something else besides checking for visual signs of missed events or previous task activities during task resumption. However, in aviation simulation studies, Helleberg and Wickens (2002) and Latorella (1998) have found that an secondary auditory task would compete with the primary visual flight task for the same mental resources and can interrupt the visual flight task entirely. This finding is consistent with auditory-visual time sharing research of Wickens and Liu (1988) and with general multiple resource theory that hypothesizes differences in dual-task performances (Wickens 2002). This previous research suggests that introducing an additional thread of auditory process may increase complexity and potentially interfere, rather than assist, primary task performance.

2.5 Instant Replay

The design approaches discussed above are still vulnerable to the effects of change blindness, since a new message in a text log could easily be misinterpreted as something that has already been dealt with upon quick glance. Similarly a user could forget to ask the verbal query system the appropriate questions, potentially missing critical information. An alternative strategy for mitigating the effects of change blindness is to provide an 'instant replay' of dynamically changing system elements (St. John, Smallman et al. 2005; Scott, Mercier et al. 2006). To minimize the necessary replay time and enable quick discovery of situation changes, systems typically allow users to replay the interrupted period at higher than real-time speed (e.g. 10 x real-time).

In St. John et al.'s (2005) research, they used a realistic simulation of air warfare as the tasking environment in order to evaluate the effectiveness of the instant replay feature to decrease interruption recovery time. They found that the instant replay tool did not help with identifying changes during the interruption, and it actually imposed a delay. The delay was a direct consequence of the participants' willingness to watch the temporal sequence even though they were not benefiting from the extra time spent on replaying the interruption sequence.

St. John et al. (2005) also investigated augmenting the primary display interface with change markers, which notified changes as they occurred. They found that while this technique was useful for detection of key events, it created clutter and was distracting. This provides a good example of the trade-off between information availability and distraction (Smallman and St. John 2003; 2005). In the end, they found that the best performing interruption recovery tool was a hybrid solution to the instant replay paradigm. Their proposed tool was named CHEX (Change History EXplicit). The task environment used an interface that consisted of a large spatial map display, a data display, and a table of critical system changes.

The CHEX tool was designed to give constant awareness information to the user about key changes that occur without overloading the primary interface with clutter. CHEX accomplishes this by instantly populating a table with new changes to the task environment as they occur, and bookmark the event in a pre-assigned row (each row represents a specific monitored event) in the table. Since the CHEX is located on a peripheral display, it bridges the Proximity Compatibility Principle (Wickens and Carswell 1995) gap by allowing the user to click on the CHEX tool to highlight the change information on the primary display. This removes clutter but allows the user to request detailed information when they needed.

Scott et al. (2006) also investigated the use of instant replay tools to assist interruption recovery in HSC task environments. In particular, they examined the impact of various replay design approaches on interruption recovery in the supervisory control of semi-autonomous unmanned aerial vehicles (UAVs). In this work, a recovery tool called the Interruption Assistance Interface (IAI) was provided on a separate, peripheral display adjoining the main UAV operator interface displays. The IAI consists of a replay window (Figure 2), an event timeline (Figure 3), and a set of animation controls (active only when animated replay is available) (Figure 4).

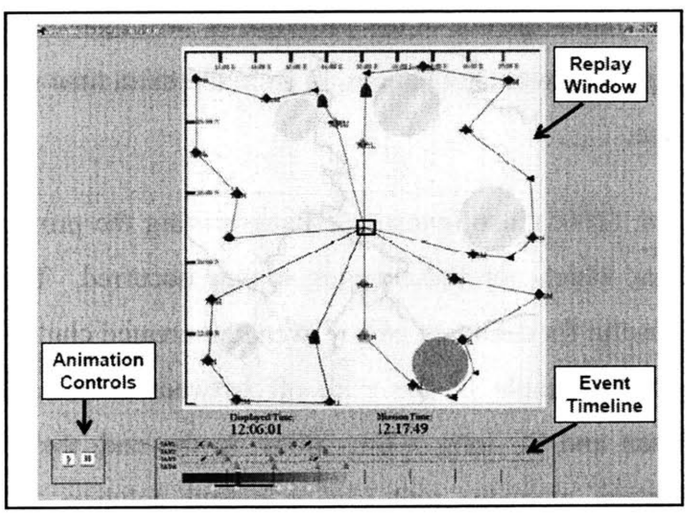


Figure 2. Interruption Assistance Interface (main display)

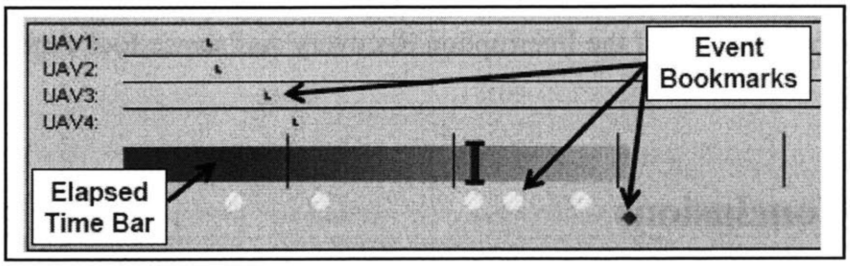


Figure 3. IAI Event Timeline

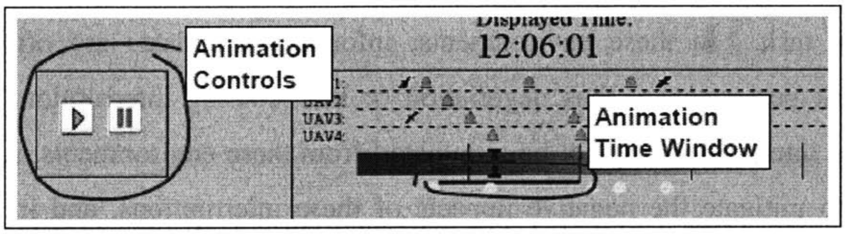


Figure 4. IAI Animation Controls

Consistent with the design recommendations made by St. John et al. (2005), the IAI is always available, peripheral, and updated as events occur in the main task environment. In the study, Scott et al. (2006) compared one version of the IAI that provided bookmarked assistance with another that provided animated assistance. The bookmark assistance displayed key events in the history of the task environment and allowed the user to jump to the discrete time periods in which the events occurred. The animated assistance allowed the user to view an accelerated animated sequence of historic events by selecting a desired time window in the event timeline.

The results from their study indicate that the IAI replay assistance is particularly useful when the participants face complex system changes after an interruption. Scott et al. (2006) recommended further investigation of tools to mitigate the disadvantages of interruptions when only simple system changes have occurred. In addition, they recommended further investigation of how to indicate time relationships between present and past system states. In particular, they recommend the integration of the replay aspects of an interruption recovery tool in the main primary display to minimize the distraction of investigating past events on a separate displays. Ironically, using a peripheral interruption recovery tool leaves the user vulnerable to missing new events that may be occurring in the main task displays. These two recommendations were inspirations to the design of the Interruption Recovery Assistance tool explained in detail in Chapter 3.

2.6 Conclusions

Supporting interruption recovery in highly dynamic, time-sensitive task environments is not an easy task. In these environments, information updates are often critical to effective task performance, thus negotiation or rescheduling interruptions may not be feasible. As interruptions cannot be eliminated from these environments, it is important to attempt to mitigate the negative impacts of these interruptions, and in particular to minimize the time and effort required for task resumption.

Based on the previous interruption recovery approaches described in this chapter, the next chapter describes the development of an interruption recovery tool designed to support team supervisors overseeing teams comprised of both humans and intelligent systems in time-sensitive military command and control task environments.

Chapter 3: Interruption Recovery Assistance Tool

The goal of this chapter is to determine the interruption recovery requirements for team supervision in a representative complex human-supervisory control team environment, and to develop an interruption recovery tool for that representative task environment. The chapter first describes the representative team task environment and the user interface displays used in this environment to assist supervisory-level decision making. Next, the chapter describes the interruption recovery requirements analysis that helped derive the design requirements for an interruption recovery aid for the team task environment. This analysis includes a cognitive task analysis for the supervisory role in the task environment and a review of design recommendations from the related literature. Finally, the chapter discusses the design of the Interruption Recovery Assistance (IRA) tool.

3.1 Team Task Environment and Experiment Platform

In order to develop interruption recovery assistance for team supervisors in a complex human-supervisory control team environment, an existing experimental platform for investigating teams of semi-autonomous unmanned aerial vehicle (UAV) operators engaged in time-critical military missions was used (Scott, Wan et al. 2007). This task environment involves supervision of both human operators and intelligent systems (i.e., multiple UAVs), thus, providing a representative complex human-supervisory control team environment.

In this task environment, a "mission commander" is given the task of supervising three UAV operators, each monitoring multiple UAVs performing surveillance and target identification. Figure 5 shows the team structure. The overall mission goal of UAV team is to secure safe passage for an important political convoy through an area of interest (AOI) which is potentially hostile.

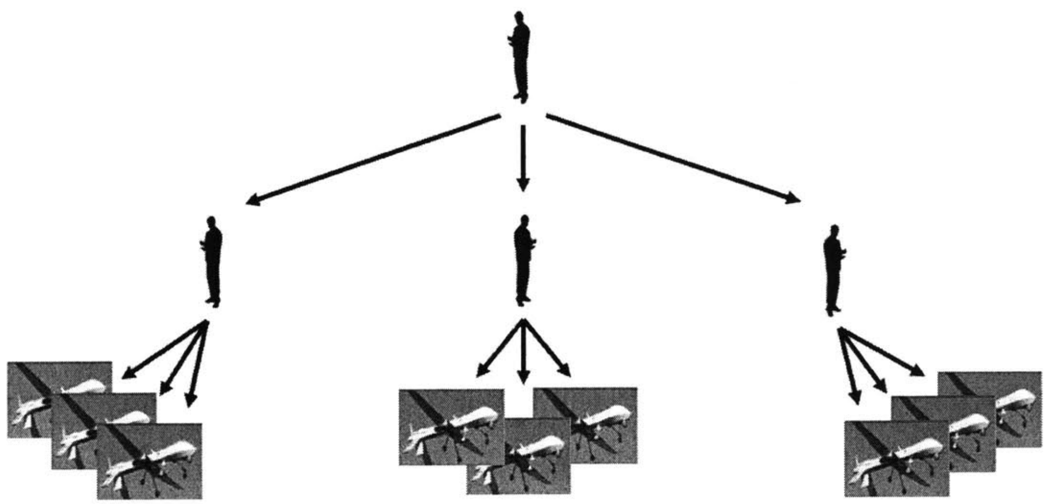


Figure 5. The UAV team structure, showing the relationship between the mission commander (top), the UAV operators (middle), and the UAVs (bottom).

In this UAV team task environment, the mission commander is responsible for ensuring the safety of the convoy and for managing the workload of the UAV operators on his or her team. To achieve these objectives, the mission commander can make several types of strategic decisions. These decisions include:

- Requesting the convoy hold its current position if the intended path is not deemed safe for passage.
- Requesting supplementary surveillance data from a nearby joint surveillance and target attack radar system (JSTARS). JSTARS is a long-range, air-to-ground aircraft surveillance system designed to locate and identify ground targets in all weather conditions.

- Re-tasking of one UAV to a different sub-AOI (requiring the handoff of a UAV between operators).

If a UAV identifies a hostile target, an external strike team is contacted to destroy the target. The scheduling of these target strikes is controlled by this strike team and is non-negotiable. Thus, if the strike team cannot destroy a target prior to the convoy entering its weapons range, the mission commander must hold the convoy until the strike team has time to neutralize the target.

The UAV team task is performed in an experimental laboratory designed to emulate a small command center, as described in Section 4.4. In this simulated command center, the UAV team mission commander has access to three large-screen displays that provide various types of mission-related information: the Map Display, the Mission Status Display, and the Remote Assistance Display, which will be detailed in the following section. In order to implement command decisions in this simulated task environment, the mission commander uses an experimental interface called the Mission Commander Interface provided on a tablet PC in the command center environment.

In this scenario, interrupting the mission commander can potentially have a huge, negative impact on the entire mission. Since it is the responsibility of the mission commander to oversee the entire operation, any situation in which a UAV or an operator is underperforming requires the mission commander to rapidly resolve the issue. Thus, if an external interruption occurs (such as providing a report to a superior or taking a phone call), it is very important that the mission commander is quickly brought up to speed on whether any events that occurred during the interruption require attention. The following sections describe the existing interfaces for this task environment. As described below, the interruption recovery assistance tool developed for this task environment are integrated directly into these existing interfaces, particularly the Map Display and the Mission Commander Interfaces.

3.1.1 Map Display

The Map Display, shown in Figure 6, visualizes geo-spatial information of relevant contacts and assets in the context of the UAV team's geographical area of interest (AOI). The black dotted lines outline the regions of responsibility for each UAV operator. The gray shading on the map indicates areas that have yet to be surveilled by the UAVs. The bottom of the interface shows a threat summary which is designed to display threat regions in relationship to past, present, and future time. This display also provides several tools for changing the level of detail displayed on the map.

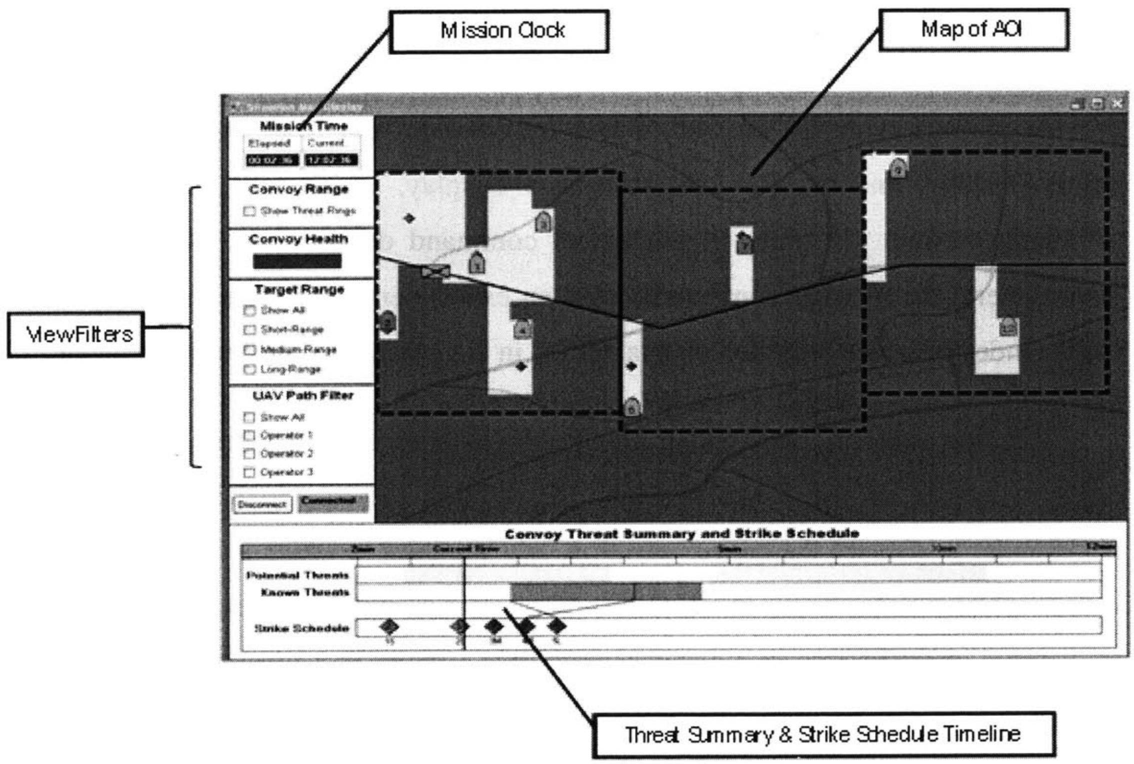


Figure 6. Map Display.

3.1.2 Mission Status Display

The Mission Status Display, shown in Figure 7, visualizes current and expected mission status information, including surveillance progress for each UAV operator, current UAV tasking information, communications link status to external resources, and operator performance. The threat summary at the top of the interface is identical to the one provided in Map Display. A message history text box at the bottom of the Mission System Display provides a record of all mission events.

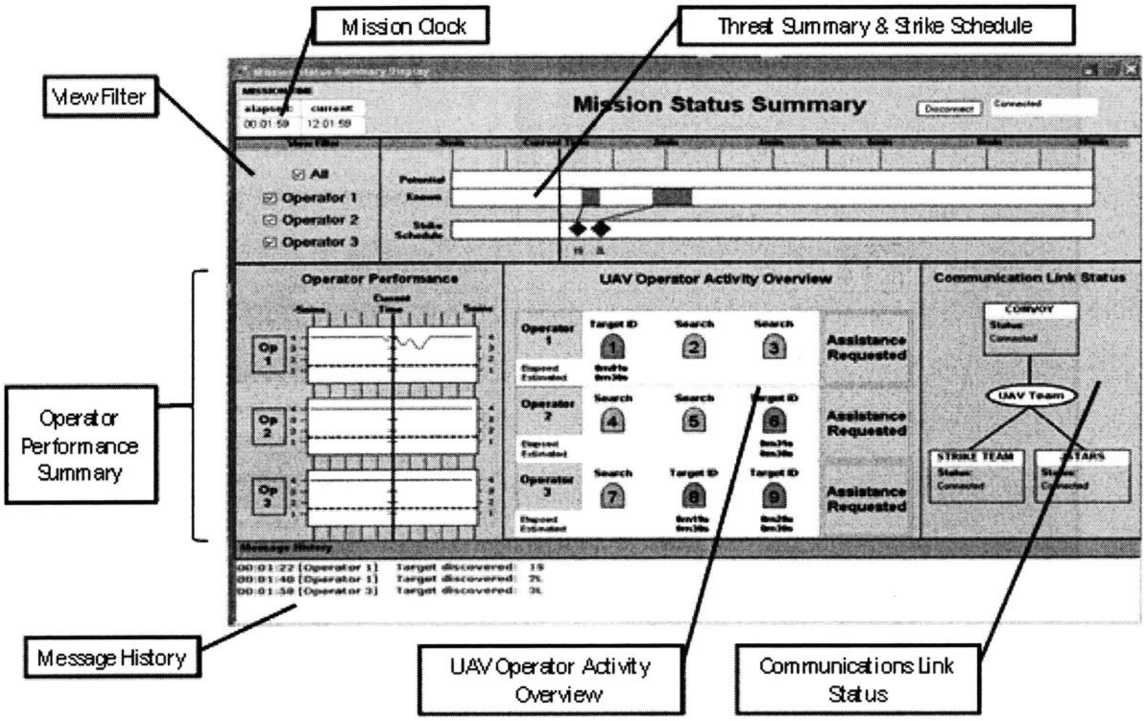


Figure 7. Mission Status Display.

3.1.3 Remote Assistance Display

The Remote Assistance Display (RAD) allows the mission commander to assist UAV operators who are having difficulties with the target identification task (Figure 8). The advantage of having this interface is that it allows the UAV operators to be co-located or remote. The mission commander can use the RAD to assist an operator in classifying a potential target that has been identified by a UAV's onboard automatic target recognition system. If an operator requires assistance with their current target identification, they can send a request to the mission commander via the RAD, which also causes a request alert to be displayed on the Mission Status Display. The mission commander can then view the UAV imagery, alter the target classification information, and submit the updated classification to the operator.

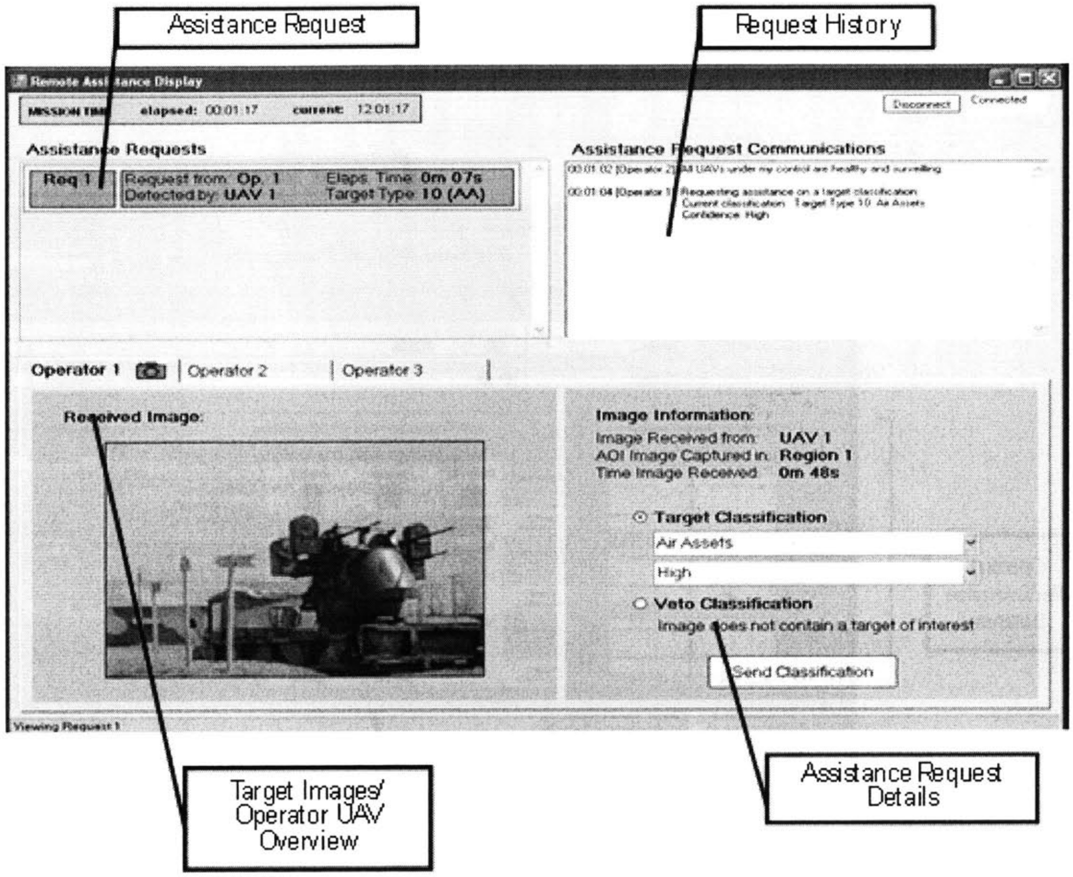


Figure 8. Remote Assistance Display.

3.1.4 Mission Commander Interface

The Mission Commander Interface, shown in Figure 9, is used by the mission commander to execute all mission decisions in the simulated task environment. Similar to the Mission Status Display, a message history is provided at the bottom of this display. This message history is a simple text log of all events that occur during the mission (e.g., convoy attacks, UAV tasking, and communication link failures), similar to the text logs discussed in Section 2.3. This message history display provides a basic level of interruption recovery support for the mission commander in this task environment.

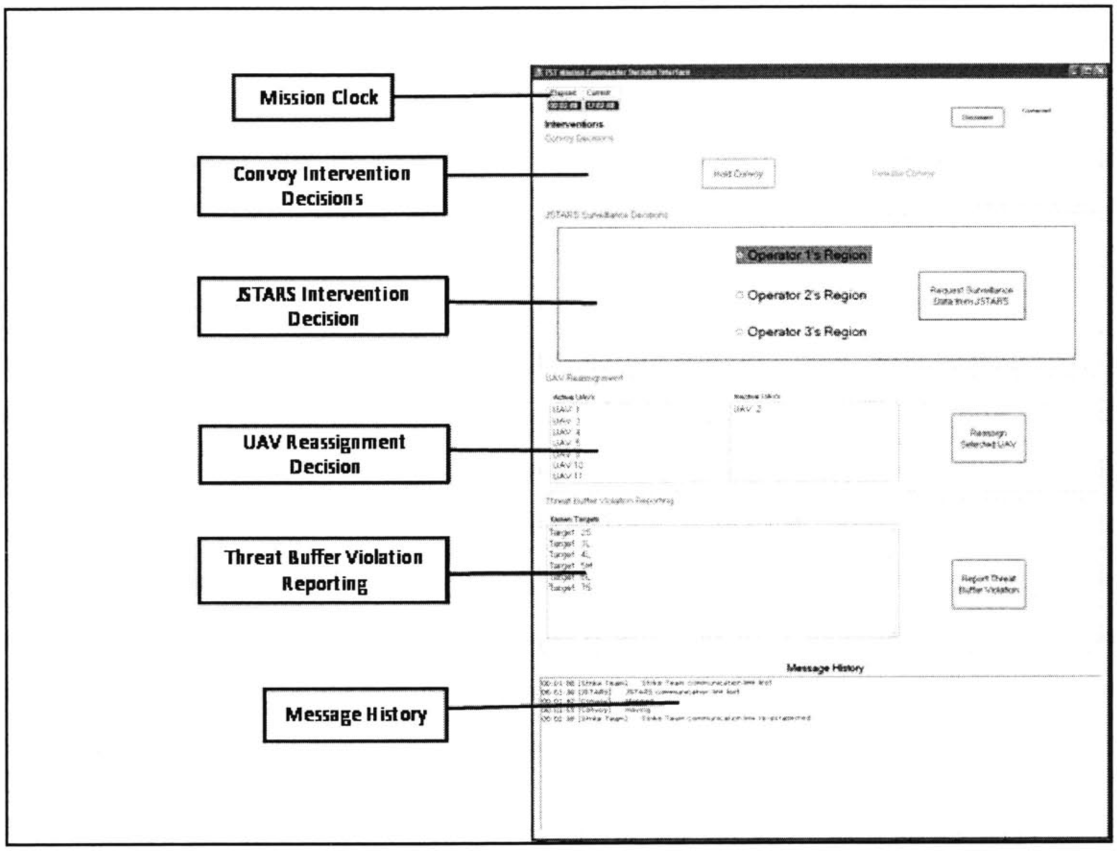


Figure 9. Mission Commander Interface.

3.2 Requirements Analysis for Assisting Interruption Recovery in the Team Task Environment

In order to inform the design of an interruption recovery tool for the UAV team mission commander, a requirements analysis was performed. The analysis involved:

- Augmenting an existing hybrid cognitive task analysis (CTA) (Nehme, Scott et al. 2006) for the UAV team mission commander to derive information and functional requirements aimed at supporting interruption recovery in the UAV team task environment.

- Drawing advice from the literature described in Chapter 2, particularly from the work on instant replay described in Section 2.5.

This section describes the details of this analysis both pieces of research and their inspiration towards generating the interruption recovery requirements.

3.2.1 Cognitive Task Analysis

The cognitive task analysis (CTA) leveraged for this thesis included augmenting an existing CTA that was created to inform the design of the large-screen mission commander interfaces described above (Scott, Wan et al. 2007).

The augmented CTA considers the effects of adding interruptions to the task scenario, and how interruptions during mission commander tasking might impact decision making. Figure 10 shows a high-level overview of the flow of events that are likely to occur in this UAV team task environment, from the mission commander's perspective (from Scott, Wan et al. 2007). The motivation for augmenting this CTA was to help identify ways that an interruption recovery tool could mitigate the effects of interruptions in the context of the critical supervisory-level decision making that occurs in this task environment. The augmented version of the CTA includes an event flow diagram (Figure 10) and four decision ladder diagrams (Figures 11-14).

The event flow diagram shows the temporal constraints of the events that can occur in a task scenario. This diagram outlines the loops, processes and decisions that occur in the UAV team task. Of particular interest to this requirements analysis are the decisions that the mission commander is required to make during the task flow (shown as diamonds in Figure 10). Each decision results in a yes or no answer, and potentially requires a complex set of analysis and planning steps to facilitate the decision process. For such complex decisions, a decision ladder is created to detail the analysis and planning aspects of the decision process. Decision ladders are used to capture the states of knowledge and information-processing activities of critical decision points during a task scenario (Rasmussen 1983). The blue diamonds in Figure 10 indicate the decisions that were deemed complex enough to expand into decision ladders for the UAV team task scenario. These decision ladders formed the basis for the interruption recovery requirements analysis.

The decision ladders were created for the command decision related to releasing (D3, Figure 11) or holding the convoy (D4, Figure 12), assisting an operator (D6, Figure 13), and reassigning a UAV asset to a different operator region (D7, Figure 14). These decision ladders were then augmented with display requirements related to assisting task resumption at various stages throughout the decision process (blue callouts in Figures 11-14). Larger versions of Figures 10-14 are provided in Appendix A, which show further details.

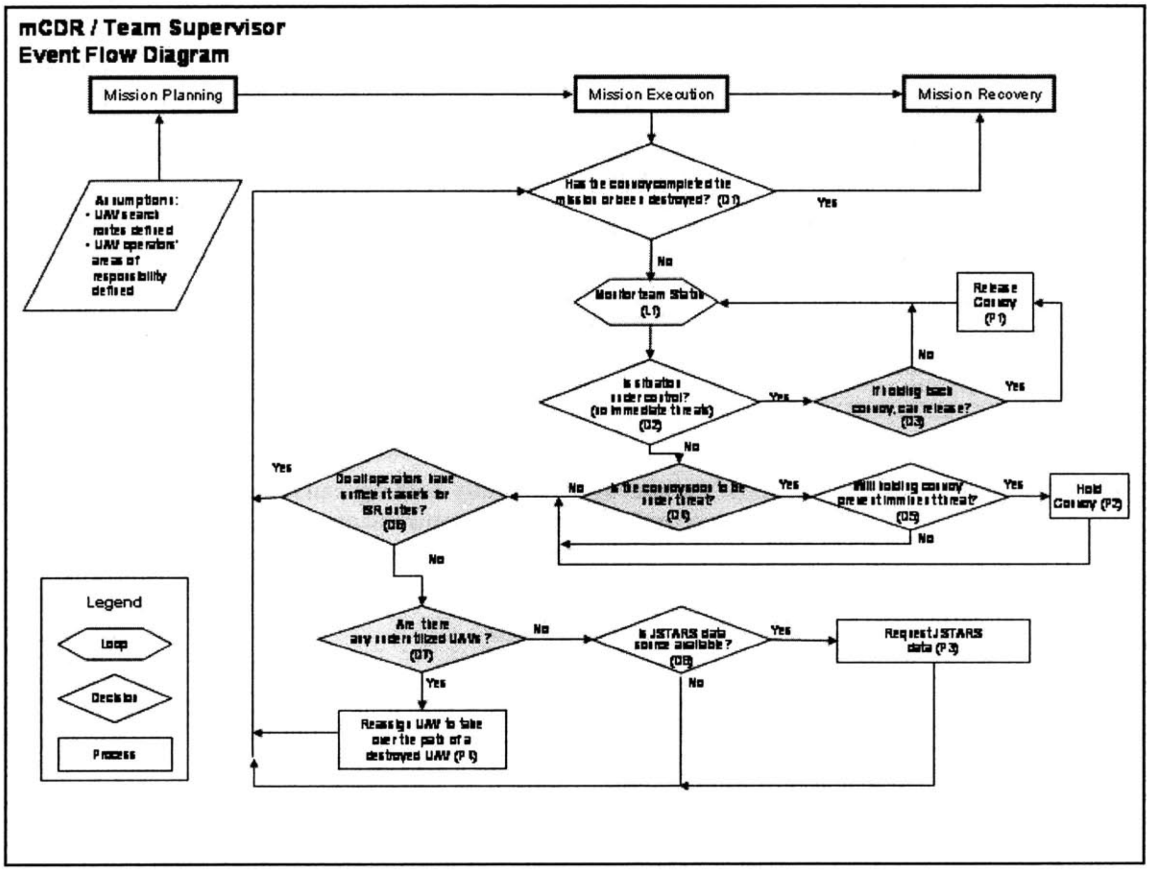


Figure 10. Event Flow Overview (from Scott, Wan et al. 2007).

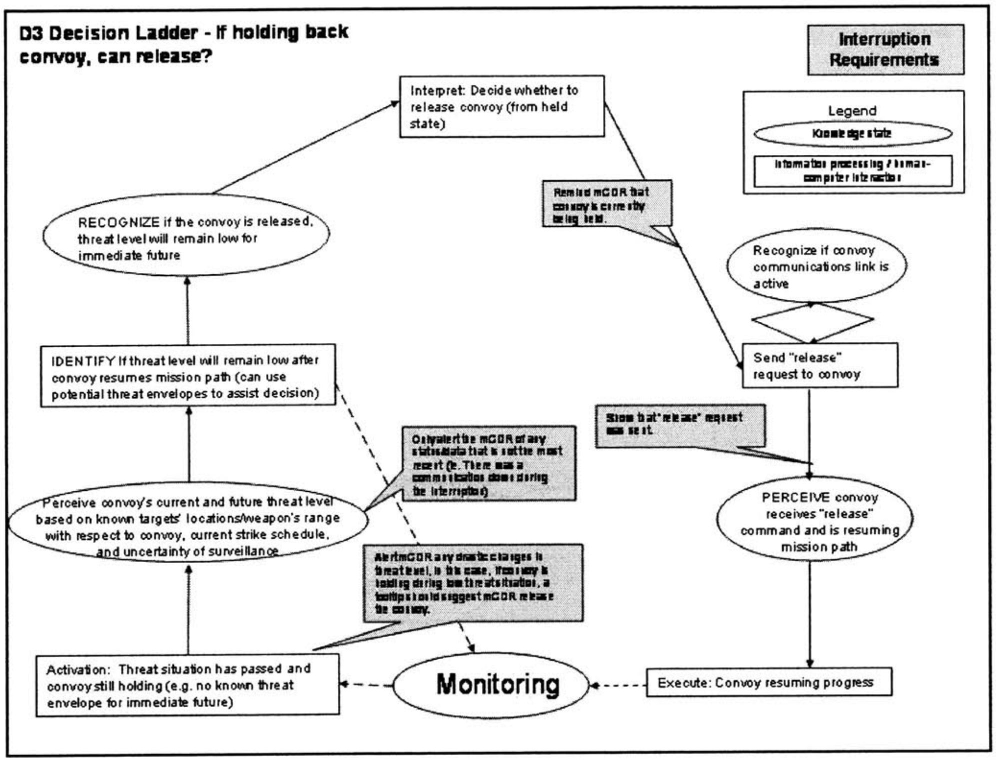


Figure 11. Decision ladder for D3 (If the convoy is currently holding, can it be released?), augmented with Interruption Recovery Requirements.

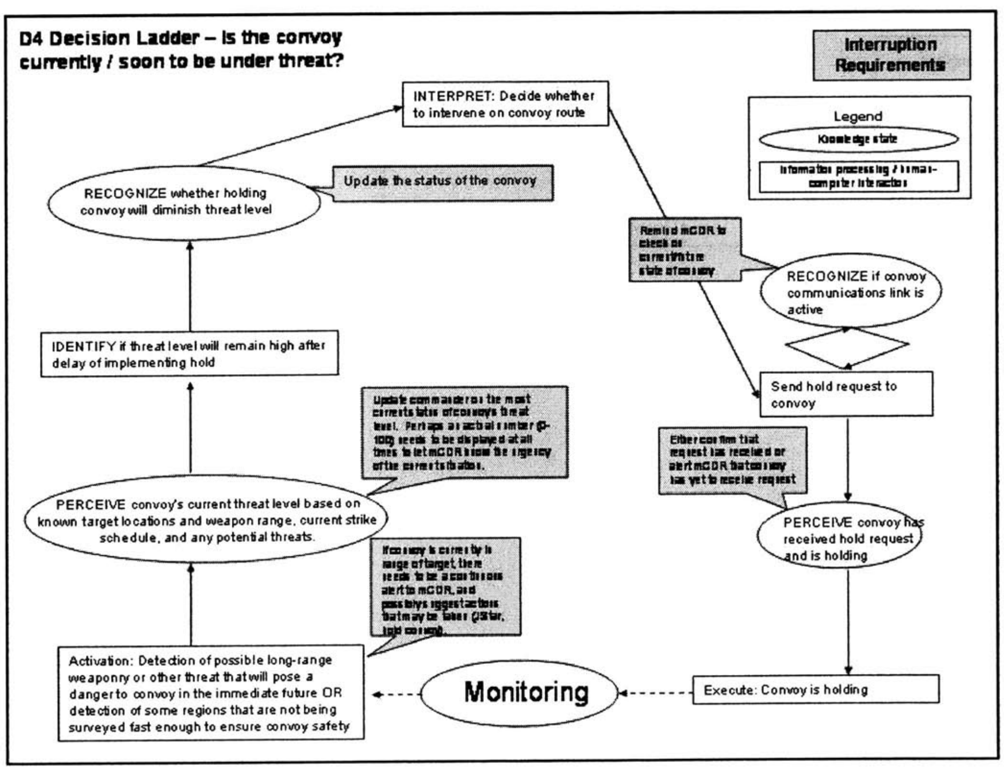


Figure 12. Decision ladder for D4 (Is the convoy in imminent danger?), augmented with Interruption Recovery Requirements.

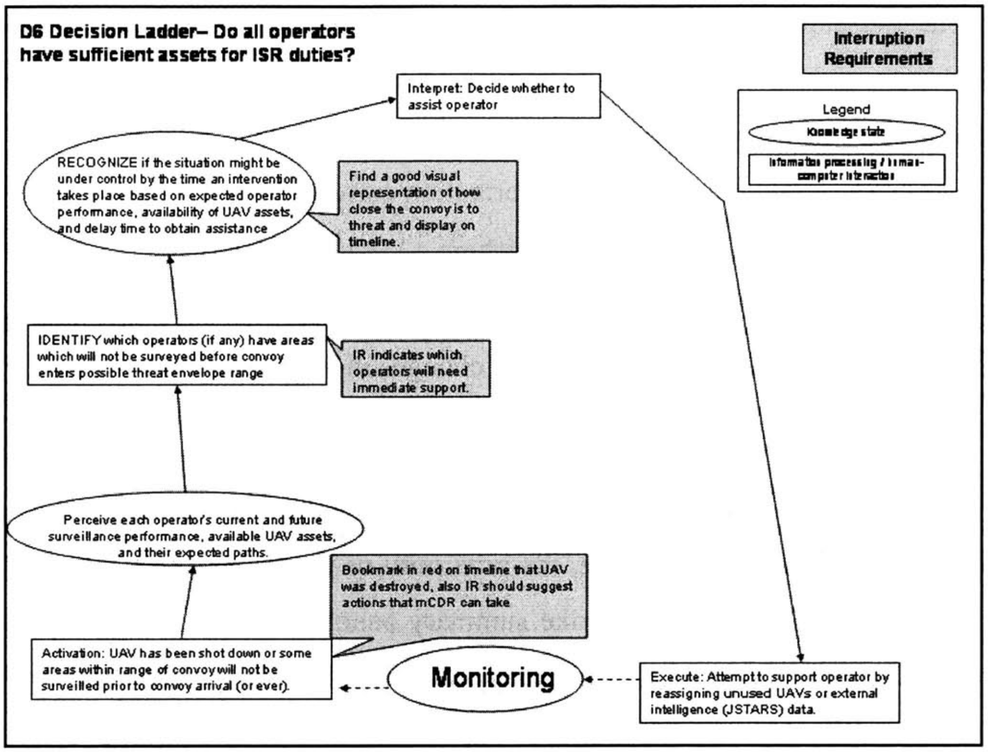


Figure 13. Decision ladder for D6 (Do the UAV operators have sufficient assets to perform the necessary surveillance?), augmented with Interruption Recovery Requirements.

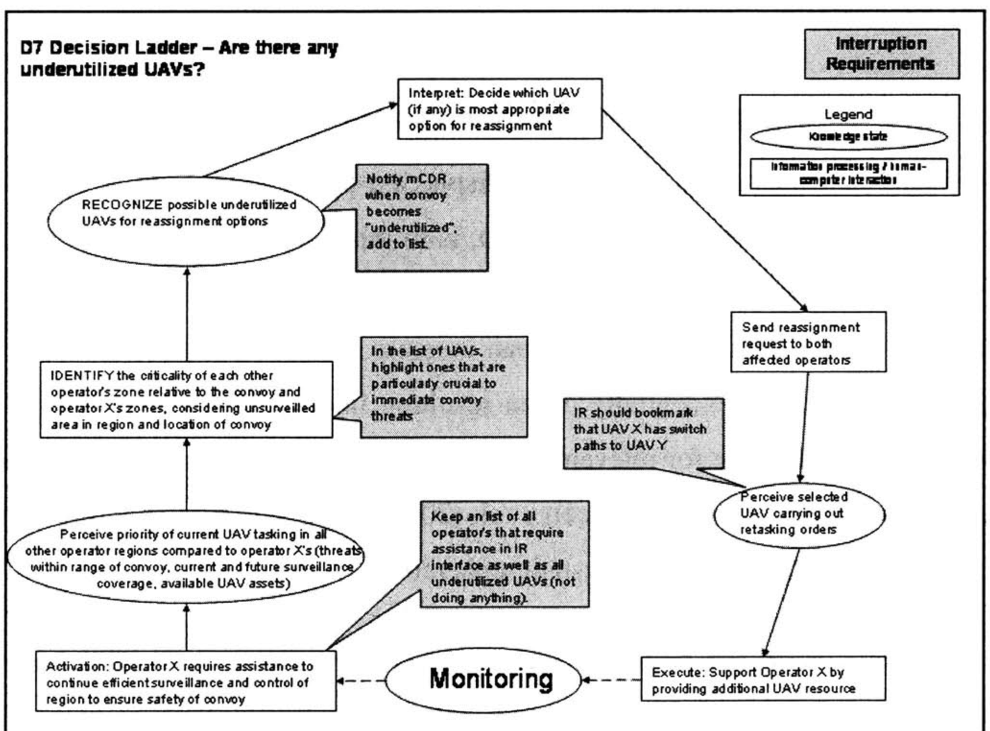


Figure 14. Decision ladder for D7 (Are any of the UAVs currently being underutilized?), augmented with Interruption Recovery Requirements.

The interruption recovery requirements identified in the augmented CTA were compiled into a list of design requirements (detailed in Appendix B). Of these requirements, the most salient and reoccurring are listed below:

- Interfaces should provide visual information on how close the convoy is to a threat.
- Interfaces should display when and where a UAV was destroyed.
- Interfaces should highlight an operator's performance if it is deteriorating.
- Interfaces should highlight any recent changes in communication status.

Some of these interruption recovery requirements are already supported by the existing decision and collaboration support provided in the large-screen mission commander interfaces. For example, the proximity of the convoy to a threat is already shown as strike envelopes on the strike summary panel of Map and the Mission Status Displays. Also, communication connection states are shown as a visual on the Mission Status Display. However, many are not, which is the subject of the design interventions discussed below. Appendix B provides further details of which requirements are satisfied by the existing tasking environment.

3.2.2 Design Recommendations from Related Literature

As previously discussed, one approach to displaying past events, such as a UAV being destroyed and a convoy approaching a threat, is to provide an animated instant replay of these previously occurring system events (St. John, Smallman et al. 2005; Scott, Wan et al. 2007). However, such instant replay can increase resumption lag because the user is forced to watch events sequentially, often resulting in time wasted watching irrelevant events along while waiting for relevant events to be displayed. To reduce the time a user wastes watching irrelevant events, Scott et al. (2006) enabled users to control the specific time periods or specific events the system replayed.

To help control the replay of past system events, Scott et al. (2006) provided a visual summary of past critical events, in the form of the event timeline (Figure 3). They found that this visual summary effectively supported decision making and interruption recovery in UAV operations. However, their results also indicated that including redundant or irrelevant visual information in the visual summary can detract from task resumption. Therefore, an effective recovery tool in this scenario should summarize only mission critical events without overloading the user with information. In particular, Scott et al. (2006) suggest that the visual summary be limited to event relevant for decision making, as identified in the previous section.

Finally, one of the findings of Scott et al.'s (2006) work was that an instant replay tool located on a peripheral display lacked the ability to indicate the relationship between the current system state and past events. They recommended that the event history be overlaid onto (or directly integrated with) the current system state. This approach would directly show past events in relation to current events.

With these design recommendations in mind, a new interruption recovery tool was developed for the UAV team task environment described in Section 3.1.

3.3 Conceptual Design of the Interruption Recovery Assistance Tool

The combination of the design recommendations discussed above led to the design of an Interruption Recovery Assistance (IRA) tool that provides an interactive event bookmark timeline that highlights past events directly on the Map Display. The IRA is fully integrated onto the tablet PC, located above the command decision controls. The design of the IRA tool is similar to the design of Scott et al.'s (2006) IAI tool, described in Section 3.2.2. However, the IRA event timeline is located on the Mission Commander Interface, and thus is integrated into the interface where command decisions are executed rather than integrated into the spatial map display.

The IRA timeline (Figure 15) contains four rows, each displaying bookmarks of different types of critical mission events: convoy attacks, UAV attacks, late strikes (i.e., targets that are scheduled to be destroyed after the convoy's current path will cross their weapons range), and communication link status changes.

Clicking on an event icon (i.e., an event bookmark) in the IRA timeline results in additional information being displayed on the Map Display, with the exception of the communication link status change events. The next section discusses the specific events that the IRA timeline displays, the design details, and the corresponding interaction design.

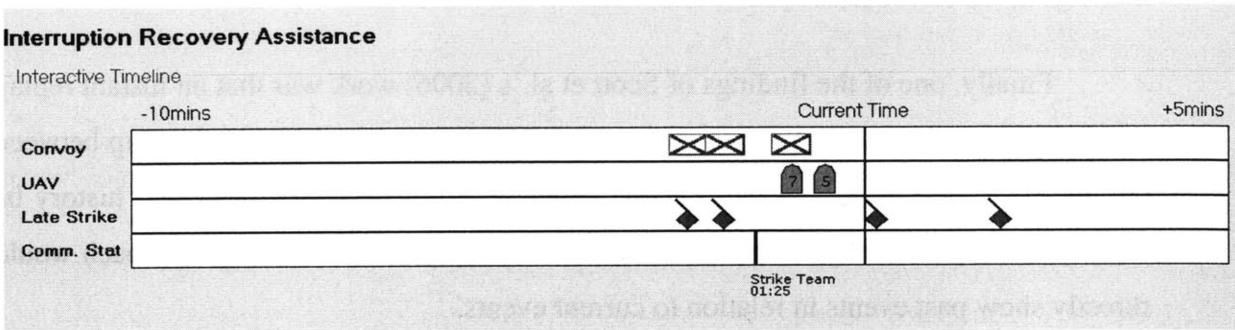


Figure 15. Interruption Recovery Assistance (IRA) event timeline.

3.4 Design Details of the IRA Tool

The events captured and bookmarked on the IRA timeline are listed in Table 1. For each type of event, the table shows the corresponding event icon that is displayed on the IRA timeline, what system event triggers the IRA tool to add the event to the timeline, and the interface changes that occur in the Map Display when a user clicks the event bookmark icon on the IRA timeline. Figure 16 shows the revised Mission Commander Interface with the IRA timeline displayed at the top of the display.

Table 1. IRA timeline events.

Icon	Event	Triggered By:	Click action:
	Convoy Attacked	Convoy gets attacked	A semi-transparent red X appears on the spatial map (Map Display) where convoy was hit.
3	UAV Destroyed	UAV is destroyed	A semi-transparent red X appears over the destroyed UAV on the spatial map (Map Display).
	Late Strike	A late strike (target will not be eliminated before convoy arrives).	A box appears around the corresponding target that will not be eliminated on the strike schedule, as well as its associated strike envelope.
Strike Team 00:30 Convoy 01:47	Comm Status Change	If any of the communication (JSTAR, Convoy, UAV) links change status (connect/disconnect).	A red dotted line is displayed if communication was disconnected. A counter displays how long it has been out. A black solid line is shown if communication reconnects, as well as a timestamp of the duration of disconnect.

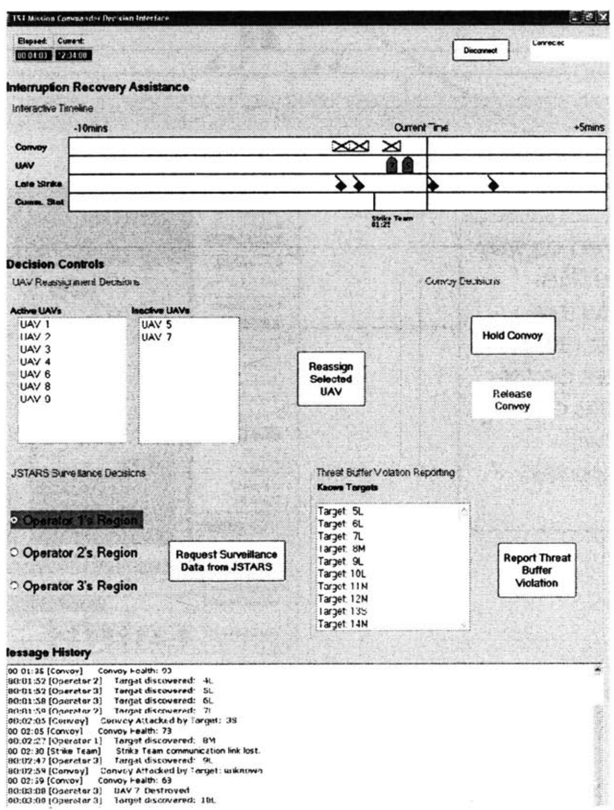


Figure 16. The IRA timeline integrated in the Mission Commander Interface.

3.5 Interaction Design of the IRA Tool

As discussed above, when the user clicks on the event bookmark icons on the IRA timeline that correspond to the Convoy Attacked, UAV Destroyed, and Late Strike events, additional information appears on the Map Display. This information is displayed for five seconds, and then fades to reveal the current state of the map. This time frame was selected based on pilot tests, which indicated five seconds was long enough for someone to select the bookmark from the tablet PC and look to the Map Display to see the change on the map. The respective change to the Map Display was available an additional few seconds as the information was fading back to its normal state. Figures 17-19 show the details of these interactions.

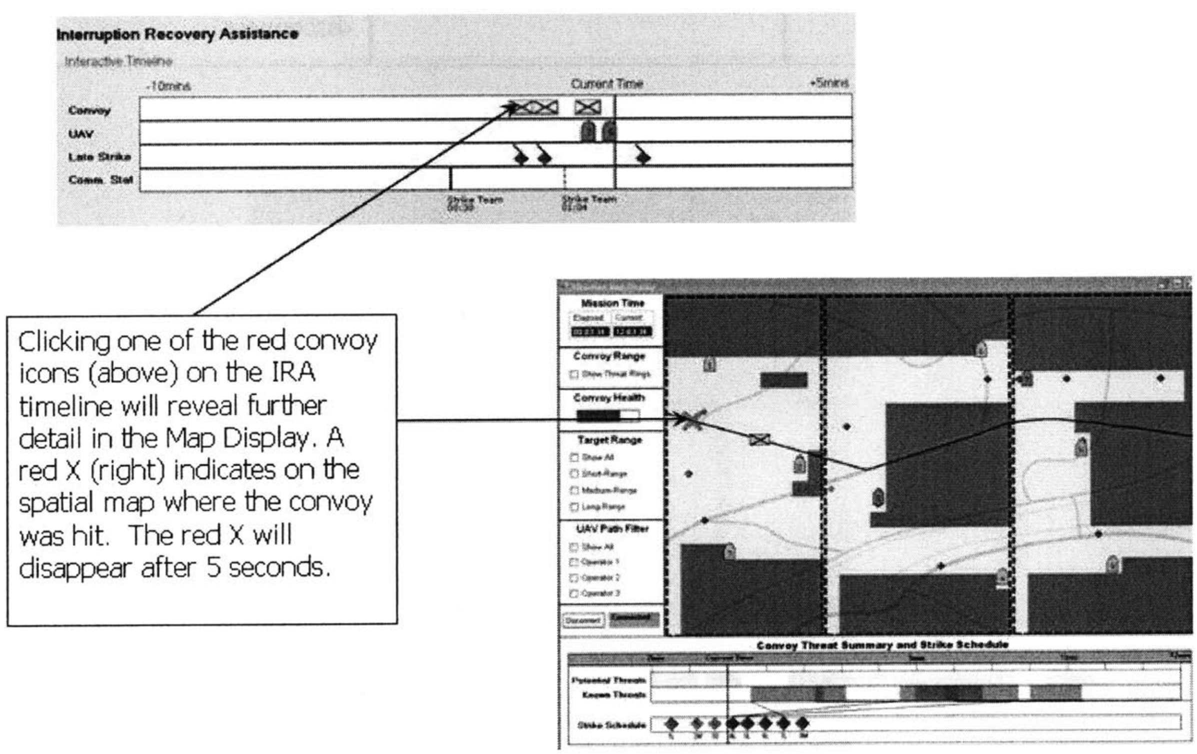


Figure 17. Revealing the Convoy Attacked event information on the Map Display.

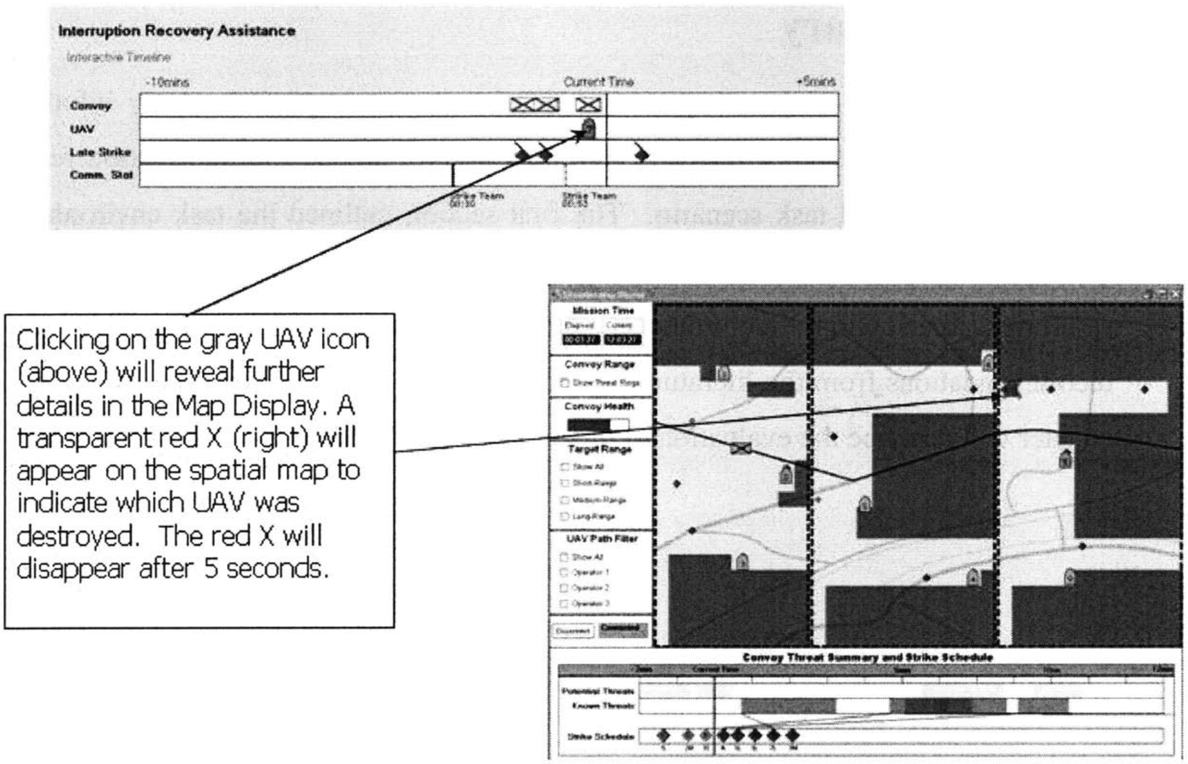


Figure 18. Revealing the UAV Destroyed event information on the Map Display.

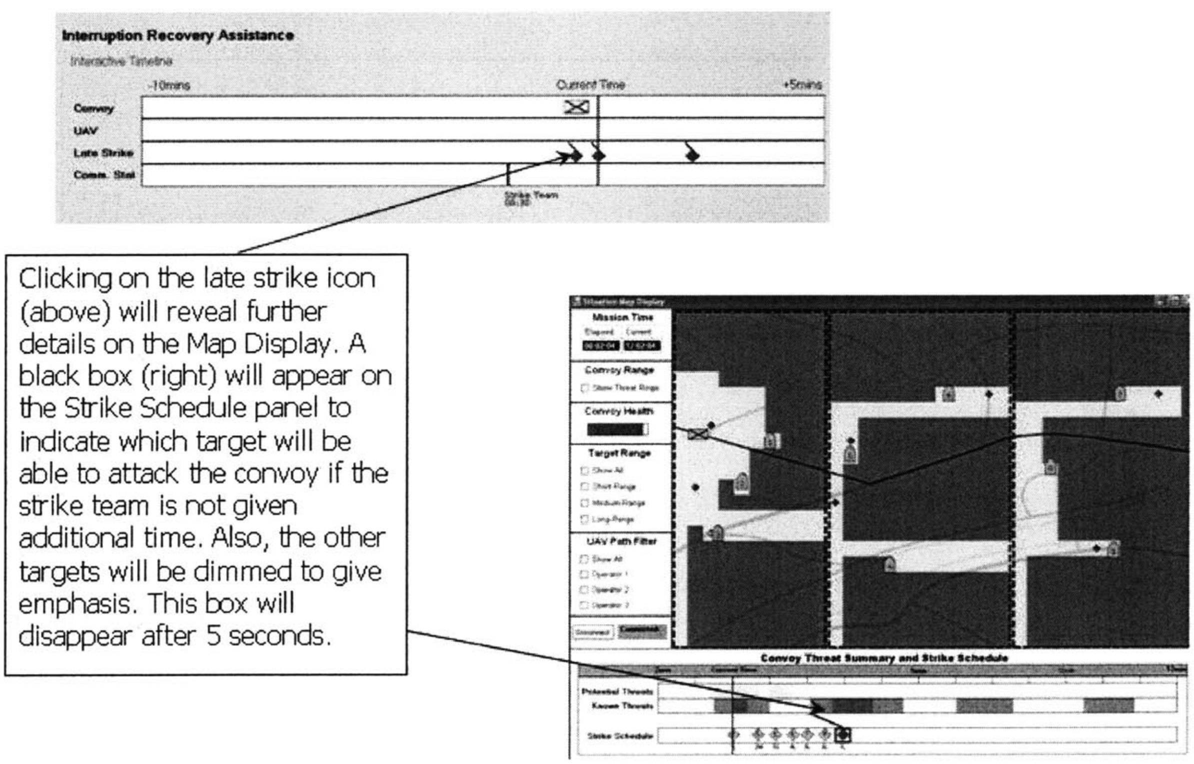


Figure 19. Revealing the Late Strike event information on the Map Display.

3.6 Summary

The main objective of this chapter was to generate interruption recovery information requirements, and design a recovery tool that would mitigate the interruption recovery time in the proposed task scenario. The first section outlined the task environment to give context to which the interruption requirements were generated. After combining the resulting interruption requirements from an augmented CTA with design recommendations from the literature, the design of the IRA tool was detailed. The next chapter will describe the evaluation of this proposed IRA tool.

Chapter 4: Evaluation Methodology

This chapter outlines the experiment and research methodology that was used to evaluate the Interruption Recovery Assistance (IRA) tool described in Chapter 3. The first sections of this chapter discuss the experiment objectives and hypotheses concerning the effects of integrating the IRA tool into the experimental platform described in Section 3.1. Next, the details of the experimental participants' demographics, experimental setup, tasks, design, and procedure are presented. Finally, the sources of data collection are explained.

4.1 Experiment Objectives

The objectives of this study focus on the use of the IRA tool to facilitate interruption recovery in a time-critical team supervisory task setting. The study aims to evaluate the effectiveness of the modifications that were made to existing team supervision interfaces and experimental task environment, in the form of the IRA event bookmark timeline and interactive event highlighting capabilities. The specific objectives are to evaluate the effectiveness of the IRA tool in reducing the negative impacts of interruptions on interruption recovery time, decision accuracy and overall task performance.

4.2 Experiment Hypotheses

4.2.1 Interruption Recovery Performance

Interruption recovery performance refers to how effectively someone can resume their task activities after an interruption has occurred. An important measure of interruption recovery performance is recovery time which is defined as "the time between leaving the secondary task and beginning the primary task after an interruption" (Trafton, Altmann et al. 2005). Recovery time depends on a person's ability to recall what they were doing prior to the interruption, as well as what they were intending to do. Additionally, in a human supervisory control task environment, they must be able to identify and comprehend the consequences of any changes that have occurred in the task environment. The IRA event timeline (Sections 3.4 & 3.5) provides a concise visual summary of the critical events that have occurred in the task environment. It is expected this event timeline will enable mission commanders to quickly evaluate the key events that occurred during the interruption in order to recover more quickly from interruptions in the environment.

Hypothesis 1: The interruption recovery time will be shorter for team supervisors who perform the experimental task with the IRA tool than for those who do not.

Another important aspect of interruption recovery performance is how well someone can resume their prior task activities. That is, how accurate are the decisions they make after an interruption or how effective are the actions they perform in order to address any pending problems in the task environment. The concise visual event summary provided on the IRA event timeline is expected to enable mission commanders to quickly and accurately ascertain any important events that have occurred in the environment to help them make informed decisions when they return from an interruption. The ability to interact with the event timeline to investigate a particular event further (Section 3.5) is expected to help mission commanders fully comprehend the events that occurred during task disruptions. Thus, it is expected that the IRA tool will help mission commanders make more accurate decisions after an interruption has occurred.

Hypothesis 2: The decisions made following task interruptions will be more accurate for team supervisors who are provided the IRA tool versus team supervisors who are not.

4.2.2 Overall Task Performance

One of the design concepts that the IRA tool incorporated was the use of a constant peripheral display, much like the CHEX tool discussed in Chapter 2. The main benefit to having a recovery tool that populates bookmarks in real time is that the information is always available and easily accessible. In addition, interaction with the IRA tool allows additional information to be temporarily displayed on the Map Display interface, which minimizes clutter and distraction. Therefore, it is foreseeable that an effective recovery tool that is always available may have positive effects to the overall task performance of the mission.

Hypothesis 3: The overall task performance scores of team supervisors who are provided the IRA tool will be higher than those team supervisors who are not.

4.3 Participants

Twelve students were recruited to participate in this experiment. Six participants were members of the Reserve Officers' Training Corps (ROTC) program, all of whom were undergraduates at MIT (majoring in political science, aeronautical engineering, and mathematics). Of the six remaining participants, four were regular undergraduate students at MIT and two were recent graduates who are doing research at MIT.

Participants were divided equally and randomly into two groups of six people. One group served as a control group, performing the experimental with no assistance for interruption recovery. The other group performed the experiment with assistance from the IRA tool. Each participant received $30 for completing the experiment.

The age range of participants was 18-23 years with an average age of 21. Only one subject out of 12 had no prior video game experience, with the vast majority playing one to four hours a week. Six out of 12 participants had supervisory experience in non-time-sensitive situations ranging from part-time job experiences to ROTC leadership programs. Appendix C outlines more details of the study demographics.

4.4 Experimental Setup

The experiment took place in an experimental laboratory in the MIT Humans and Automation Laboratory (Figure 20). The laboratory contained three 42-inches (1024x768 pixel), wall-mounted interactive plasma displays. These large displays contained the team supervisory displays (i.e., the Map, Status, and Remote Assistance Displays) described in Section 3.1. The laboratory door was adjacent to a large viewing glass through which the experimenter could monitor the participant's activities.

A 14.1-inch, Fujitsu tablet PC, containing the Mission Commander Interface described in Section 3.1, was located on a 38-inch high wooden podium that was positioned near the large displays. There was an additional computer workstation in the room that was used for the computer-based tutorial part of the experimental task training.

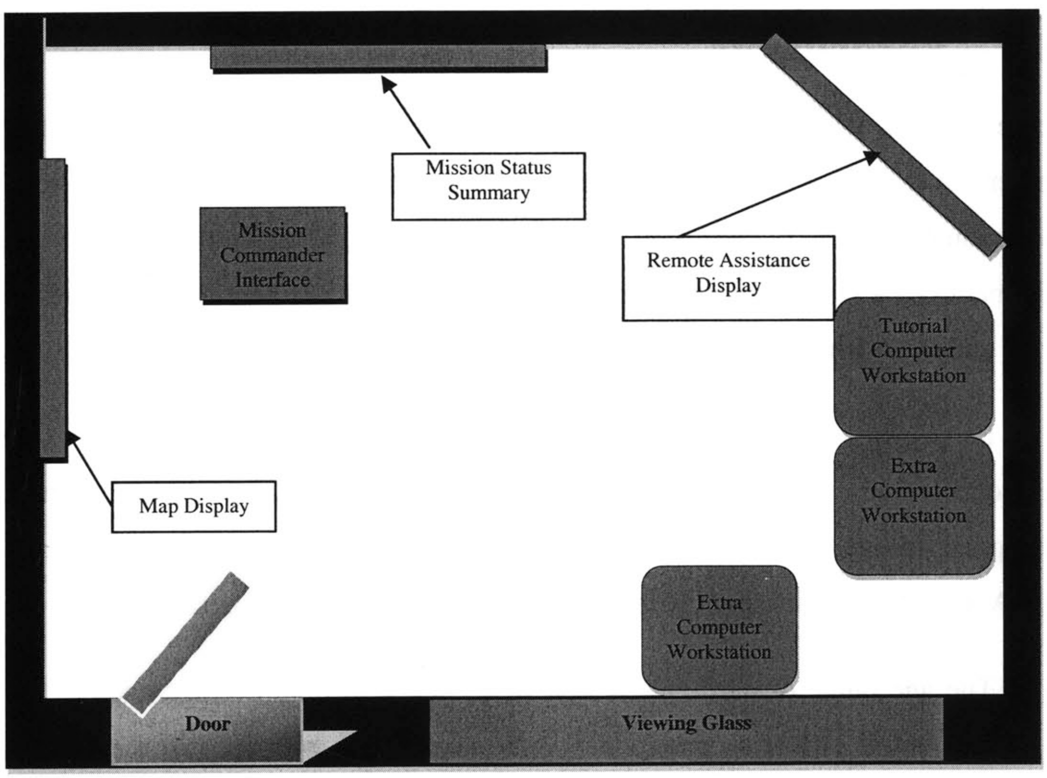


Figure 20. Experimental Facility

All computers were Microsoft Windows-based personal computers (PCs). The four experimental interfaces (i.e., the large-screen and the tablet PC displays) were developed in the Microsoft C# .NET programming language and the computer-based tutorial was shown as a Microsoft PowerPoint slide show.

The simulated task environment was run from a simulation computer. This computer acted as the server computer and it was placed adjacent to the viewing glass so that the experimenter could monitor the mission progress. Using a C# library called GroupLabs.Networking developed by researchers at University of Calgary (Boyle and Greenberg 2006), the various software modules located on the different experimental computers were able to pass objects and share data through a networked, TCP connection.

4.5 Experimental Tasks

4.5.1 Primary Task

For the primary task, the participant was asked to assume the role of the mission commander of the UAV team task described in Section 3.1. The individual UAV operators, who monitor and identify targets that UAVs discover, are simulated as remote participants in the experimental task environment. Occasionally, a potential target identified by a UAV is actually non-threatening to the mission and is disregarded during the target identification process. The mission commander can choose to assist the remote operators in the target identification task through the RAD (Figure 8).

The mission commander is responsible for ensuring the safety of the convoy and for managing the workload of the UAV operators on the team. As described in Section 3.1, the mission commander can make several strategic decisions to achieve these mission objectives, including holding or releasing the convoy from its current position if the intended path is not deemed safe for passage, requesting supplementary surveillance data from JSTARS, and re-tasking of one UAV to a different operator region.

A test session took 15-20 minutes to complete when the three one-minute interruptions were included.

4.5.2 Secondary (Interruption) Task

For each interruption, the participant was asked to vacate the experimental laboratory and complete a secondary task. The task was given on a single sheet of paper and ranged from mathematic problems, logic puzzles, and reading and comprehension. The participants were given one minute to complete the secondary task. They were then asked to return to the primary task, even if they were not finished. If a participant was finished early, they were asked to sit and wait until the full one minute had passed. The three sheets were presented in the same order to the participants (Appendix D).

When the participant returned to the experimental laboratory after an interruption, they were required to fill out an incident report (Appendix E). The incident report is a blank sheet of paper, in which the subject is asked to write down any observed changes in the mission status since they were gone. The purpose of the incident report is to detect any change blindness incidents, as well as assess the general task performance of the participants. The incident report was encouraged to be filled out as soon as the participant was able to stabilize the mission after recovery.

4.6 Interruption Design

All participants were interrupted three times during the experimental trial. An interruption was announced by knocking on the laboratory door. The participant was asked to drop whatever they were doing and leave the room. Outside the room, the participant performed the secondary task. Each interruption lasted for one minute and participants did not have prior knowledge of when the interruptions would occur.

Table 2 describes the timing of each interruption during the experimental trial. It also describes the critical events that occurred in the primary task environment during each interruption. Note that the first two interruptions were initiated consistently at the same preset times for all participants. However, the precise time at which the third interruption occurred varied from participant to participant, to ensure that when the participant returned from the interruption, a certain set of events would have occurred in the environment. Specifically, the time was adjusted to ensure the convoy was approaching an area of unsatisfactory surveillance.

Table 2. Description of Experimental Interruptions.

Int #	Begin Time of Interruption	Status of mission prior to interruption	Critical Event Changes Occurring During Interruption:
1	1:10	Convoy HOLD disabled (cannot be held). No late strikes, mission is stable. UAVs are surveilling.	UAV identifies a late strike target. When participant returns, convoy HOLD is enabled and they have 15 seconds to hold convoy before it will be attacked.
2	5:15	Convoy HOLD disabled. No late strikes, mission is stable. UAVs are surveilling.	UAV 5 is destroyed, and JSTARS communication link is disabled. When participant returns, convoy HOLD is enabled they have 20 seconds to hold convoy and reassign another UAV.
3	~10	UAVs are taking long time to survey targets that are in the path of the convoy. The convoy is approaching a larger unsurveilled area (many yellow, potential threats).	The participant returns from the interruption when the convoy is approaching an extensive unsurveilled region. The correct decision is to use JSTARS because all the UAVs are taking a long time to identify targets.

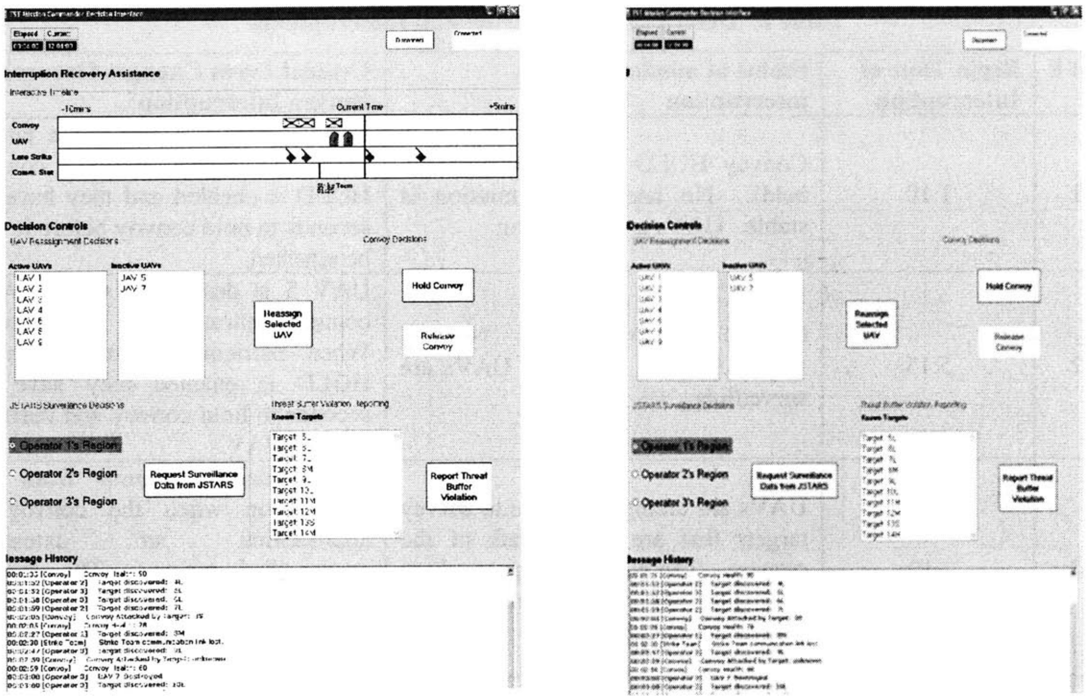
4.7 Experiment Design

The experiment used a 2 (Assistance Type) x 2 (Decision Difficulty) mixed design, repeated on the Decision Difficulty factor and between subjects on the Assistance Type factor.

4.7.1 Independent Variables

The two independent variables of interest in this experiment were Assistance Type and Decision Difficulty.

Assistance Type refers to whether computer-based interruption recovery assistance was provided to participants. Two levels of Assistance Type were included: Assistance and No Assistance. In the Assistance condition, participants were provided the IRA tool in the primary task setup (Figure 21a). In the No Assistance condition, participants performed the primary task without the IRA tool. Thus, participants used a simplified version of the Mission Commander Interface, which did not contain the IRA timeline (Figure 21b).



(a) **(b)**

Figure 21. Mission Commander Interface (a) with Assistance , (b) with no Assistance

Decision Difficulty refers to the complexity of decision that participants faced when they returned to the primary task after each interruption. Two levels of Decision Difficulty were used: simple and complex. In the simple condition, only a one possible decision was appropriate to address the current situation. In the complex condition, several decisions could possibly be made to address the current situation; however, only one decision most appropriately satisfies the UAV teams' mission objectives.

An example of a simple decision is that after an interruption occurs, the convoy is approaching a target (which was discovered during the interruption) that will not be destroyed on time. Thus, the only response would be for the mission commander to hold the convoy immediately to allow the strike team time to eliminate the target.

An example of a complex decision is that while the mission commander was gone, one of the UAVs was destroyed and the convoy is approaching the weapons range of an unsurveilled area, and is in a potential threat situation. Also, during the interruption, the JSTARS communication link was disconnected. Therefore, when the mission commander returns from the interruption, they must observe that (a) the convoy is approaching a potential threat region and (b) they cannot use JSTARS to obtain surveillance information about the unsurveilled area. Although the mission commander could chose to wait until the JSTARS communication link comes back online, the optimal decision would be to quickly reassign another UAV to the area, and to hold the convoy until the potential threat region is surveilled. In general, a complex decision requires the mission commander to choose the most optimal strategy from a few that are acceptable.

4.7.2 Dependent Variables

Three dependent variables were used in this study to measure interruption recovery and overall task performance. These variables are detailed in this section.

Interruption Recovery Time refers to the time from when a participant returns to the primary task until the time they take their first primary task action.

Decision Accuracy refers to the accuracy of any decisions participants made following an interruption. The primary task actions performed by participants after each interruption were assigned a decision accuracy score, which was determined as follows: 0 = no action taken; 1 = actions represented a suboptimal decision; 2 = actions corresponded to an optimal decision.

Convoy Health refers to the percentage of convoy health that remained at the end of a mission. The primary objective of the mission is to move the convoy through the terrain as quickly and safely as possible. Therefore, the best measure of a participant's success in meeting the primary objective is a function of the safety of the convoy and the amount of time required to pass through the AOI. The convoy health was designed to be the main measure of mission performance and was a function of the two variables aforementioned: time and health. There are two ways in which a convoy loses health: a) the convoy is attacked by a target (decrease in health), and b) the convoy's position is held by the mission commander (increase in time).

4.8 Experiment Procedure

The experiment began with participants completing an informed consent form (Appendix F) and a Demographic survey (Appendix G). The demographic survey assessed participants' educational background, military experience, prior experiences with time sensitive command and control operations, color blindness, and experience playing video games.

Next, participants completed a computer-based PowerPoint tutorial that outlined their experimental tasks and provided an overview of the experimental task interfaces. Participants in the Assistance condition were given a tutorial with several additional slides describing the IRA tool (Appendix H). When the participants were finished with the PowerPoint tutorial, they were given verbal reminders on their mission task and any further confusions or questions were addressed (Appendix I).

Participants then completed two practice sessions in the experimental task environment. In the first practice session, the participant was asked to observe changes of a partial scenario (shortened to only two operator regions). The subtle functionalities of the interfaces were explained and the participant was asked questions to test their comprehension. This session took approximately 10 minutes.

The second practice session was a complete task scenario where the participant was left alone in the experimental laboratory to perform the task. In this session, the participant was interrupted once to complete a secondary task and their performance results were not measured. The goal of this session was to give the participants a chance to acclimate to the interfaces and perform the secondary task and incident report following the interruption. This session took approximately 15 minutes.

For the secondary task (where participants completed paper-based exercises during the interruption period), participants were asked to vacate the room through the door and sit at a round table adjacent to the experiment room.

An experimental trial took 15 to 20 minutes to complete, depending on skill level. The participant was interrupted at three different times, as discussed in Table 2.

The entire experiment lasted approximately 90 minutes per participant including filling out paperwork (participation agreement, surveys), viewing the PowerPoint tutorial and performing the task sessions.

4.9 Data Collection

Three sources of data were collected during the study:

Computer Log File: The simulation server generated a text file which logged all user activities and mission status changes. These data log files included all user interactions with the interfaces, such as any decisions made through the Mission Commander Interface, any interaction with the IRA interactive timeline, and any toggling on or off display view filters. Each logged event was time-stamped. The current mission status of the UAVs and convoy was also recorded with each change in state (UAV moving, convoy holding, convoy hit, etc.). These log files were used to determine participants' interruption recovery time, decision accuracy, and general interaction patterns.

Demographic Questionnaire: Prior to starting the tutorial, each participant was asked to complete a demographic questionnaire. This questionnaire gave an overall understanding of the demographic of the participant and any prior experience that may be relevant to the experiment, such as team supervision, military training, and video game playing experience.

Interview Notes: After the experimental trials were finished, each participant was asked a series of questions. It was decided to gather this data verbally to ensure that participants did not rush through this last activity after such a lengthy study. The interview was designed to obtain an understanding of the participant's usage pattern of the IRA and their observations of various interruptions, see Appendix J for the list of interview questions.

Chapter 5: Results & Discussion

This chapter presents the experimental results of the user study described in Chapter 4. The study included two independent variables: Assistance Type (with assistance (IRA) or without assistance (no IRA)) and Decision Difficulty (simple or complex). Several dependent variables are considered in the statistical analysis of the data in order to capture and measure interruption recovery performance and overall task performance, as discussed in Section 4.7.2. The analysis of these variables is discussed in the first part of this chapter. Then, the findings from the post-experiment interview and observational data are presented. These findings help elucidate the statistical results, and have implications for the design of supervisory-level interruption recovery tools.

5.1 Overview of Performance Results

The independent variable decision difficulty was a within-subjects factor that had two factor levels collected within a single trial for each participant. That is, within each trial participants faced both simple and complex decisions. However, one of the dependent measures used in the analysis concerns overall task performance, which produced only one data point per participant. Therefore, the general linear model used for this analysis includes both single and two-factor analysis of variance, as applicable. The independent factors were considered to be fixed and the participants a random factor. In addition, since previous studies in the experimental task environment indicate that military experience can impact task performance, the general linear model included this as a blocking factor. Appendix K details the statistical tests used in the data analysis reported in this chapter. For all reported results, $a = 0.05$ unless otherwise stated. For all parametric tests, the data met homogeneity and normality assumptions.

Several unexpected factors resulted in data collection and task performance issues during interruption three. The optimal decision that participants could make after this interruption was to request JSTARS surveillance data. However, several people experienced technical difficulties with this display feature, and the command was not realized in the simulation environment, affecting the quantitative data recorded for their session. Also, the mission situations post interruption three varied due to differences in participant behaviors. As explained in Section 4.6, the timing for interruption three was varied across participants in an effort to ensure that a certain set of mission events had occurred. However, based on their task performance, participants often experienced a different mission situation upon their return. For some participants, this resulted in there being no critical mission issues to address and, therefore, no decision to be made upon their return, invalidating their interruption recovery performance data. In light of these issues, the quantitative data analysis presented below omits any interruption recovery performance data for interruption three. Also, the convoy health score used in the data analysis was adjusted to a consistent time between interruptions two and three for the analysis of overall task performance.

5.2 Interruption Recovery Performance

5.2.1 Interruption Recovery Time Performance

As outlined in Section 4.7.2, interruption recovery time refers to the time from when a participant returns to the primary task until they take their first primary task action. This measure represents the time it takes a participant to reorient themselves to the primary task, to understand any critical changes, and decide what actions should be performed in response to those changes. Participants' interruption recovery time was analyzed as a 2 x 2 repeated measures analysis of variance (ANOVA) comparing assistance type (assistance or no assistance) and decision difficulty (simple or complex), blocking for military experience.

Military experience had a marginally significant effect on interruption recovery time ($F(1,9)=5.077$, $p=.054$). On average, non-military participants recovered from interruptions quicker than military participants (non-military: M=13.4s, SD=5.4s;

military: M=20.4s, SD=6.6s). No significant differences in interruption recovery times were found for either the assistance type ($F(1,9)=1.173$, $p=.307$) or decision difficulty ($F(1,10)=1.447$, $p=.257$) main effects. However, a marginally significant interaction effect between these factors was found ($F(1,10)=4.476$, $p=.06$).

The impact of assistance type on interruption recovery time was inconsistent across decision difficulty levels. This interaction effect was particularly apparent for military participants. With assistance, military participants recovered slower when they faced a complex decision than when they faced a simple decision. In contrast, without assistance military participants recovered quicker when they faced a complex decision than when they faced a simple decision. The box plot in Figure 22 demonstrates this effect by showing the median interruption recovery times as well as the quartiles and extreme values for each assistance type and decision difficulty levels, for non-military and military participants. Table 3 summarizes the key statistics.

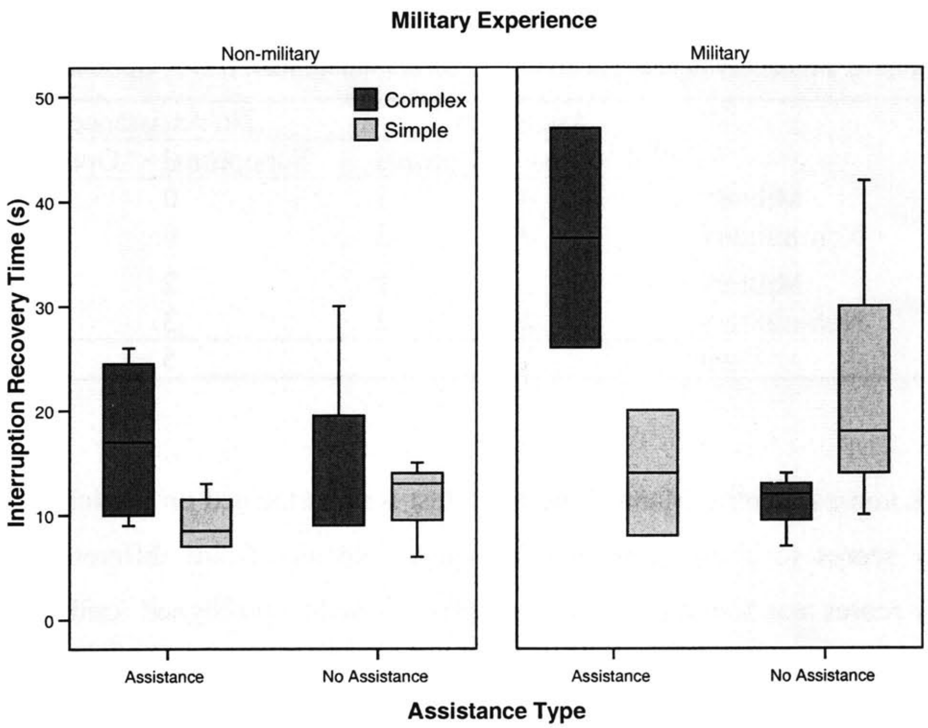


Figure 22. Interruption recovery time by military experience.

Table 3. Interruption recovery time summary.

		Assistance			No Assistance		
		Mean	Median	Std Dev	Mean	Median	Std Dev
Simple	Military	14.00	14.00	8.48	23.33	18.00	16.65
	Non-military	9.25	8.50	2.87	11.33	13.00	4.73
Complex	Military	36.00	36.50	14.85	11.00	12.00	3.61
	Non-military	17.25	17.00	8.50	16.00	9.00	12.12

5.2.2 Decision Accuracy Performance

As discussed in Section 4.7.2, the first set of primary task actions participants performed after each interruption was assigned a decision accuracy score. This score was determined as follows: 0 = no action; 1 = actions corresponded to a suboptimal decision; 2 = actions corresponded to an optimal decision. Table 4 summarizes the frequency of each decision accuracy score across assistance type and decision difficulty levels for military and non-military participants.

Table 4. Frequency of decision accuracy scores (Suboptimal: DA=1, Optimal: DA=2).

		Assistance		No Assistance		
		Suboptimal	Optimal	Suboptimal	Optimal	Total
Simple	Military	0	3	0	2	5
	Non-military	0	3	0	4	7
Complex	Military	1	1	2	1	5
	Non-military	2	2	3	0	7
	Total	3	9	5	7	

A non-parametric Mann-Whitney U test was performed on participants' decision accuracy scores to compare assistance types. No significant difference in decision accuracy scores was found (U=12.00, p=.241). A Wilcoxon Signed Rank Test was then used to analyze the differences between decision difficulty levels. This test found that participants were significantly more accurate when faced with a simple decision than a complex decision after an interruption (Z=-2.828, p=.005). Figure 23 illustrates this difference between decision difficulty levels in both assistance types. This figure also shows that for complex decisions, there is a trend for improved decision accuracy when participants were provided assistance. Figure 24 illustrates the comparison between assistance types for military and non-military participants faced with a complex decision. This bar chart shows a trend for military participants to make more accurate decisions overall, and a trend for non-military participants to perform as well as their military counterparts when provided assistance.

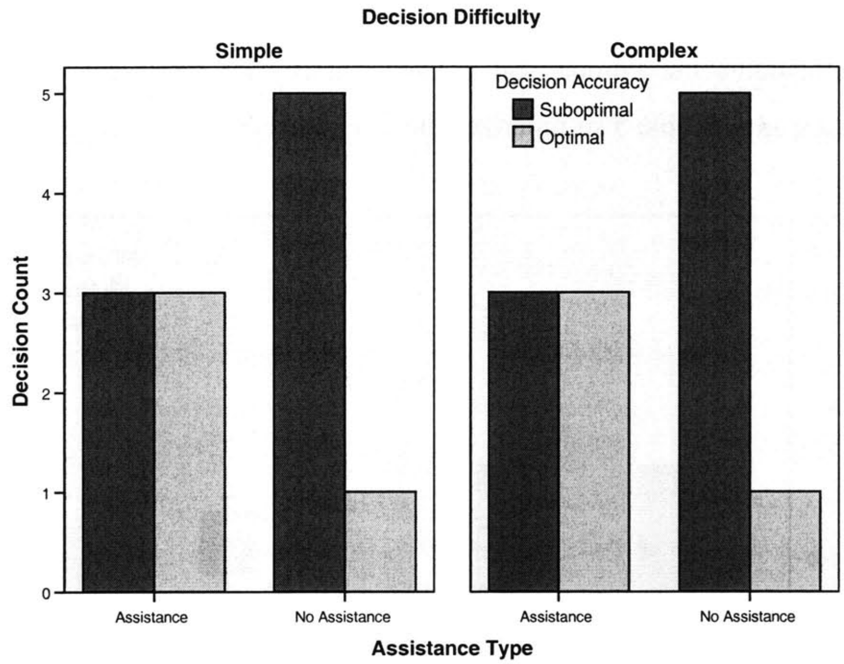


Figure 23. Decision accuracy score.

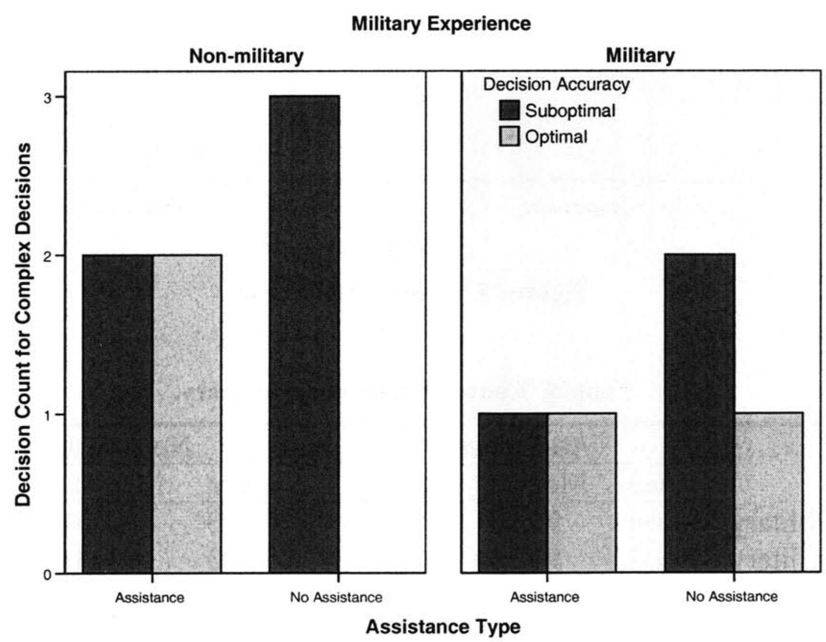


Figure 24. Complex decision accuracy scores by military experience.

5.3 Overall Task Performance

The convoy health score was used as the metric for overall task performance, as discussed in Section 4.7.2. In order to determine the impact of assistance type on this performance measure, a one-way ANOVA, blocking for military experience, was performed. No significant differences were found in convoy health scores for either military experience ($F(1,9)=0.296$, $p=.600$) or assistance type ($F(1,9)=0.580$, $p=.466$). Figure 25 illustrates the comparison between assistance types for non-military and military participants. Table 5 summarizes the key statistics.

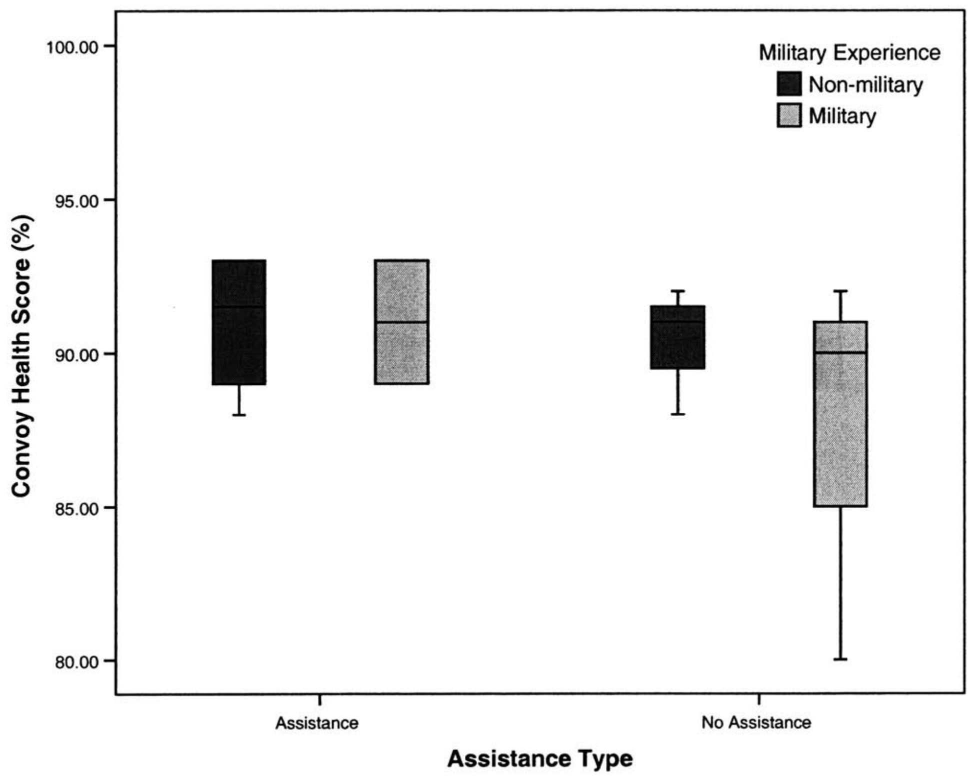


Figure 25. Convoy health score.

Table 5. Convoy health score summary.

	Assistance			No Assistance		
	Mean	Median	Std Dev	Mean	Median	Std Dev
Military	91.00	91.00	2.83	87.33	90.00	6.42
Non-military	91.00	91.50	2.45	90.33	91.00	2.08

5.4 Discussion of Performance Results

This section discusses the statistical results presented above and compares them to the hypotheses outlined in Section 4.2.

5.4.1 Interruption Recovery Performance

Interruption recovery performance refers to how quickly and accurately participants' resumed the primary task following the experimental interruptions. With respect to interruption recovery time, the results did not indicate a statistically significant difference between assistance type levels. However, the marginally significant difference found for the interaction between assistance type and decision difficulty levels indicates that the IRA tool had some influence on recovery time. The data also indicated a marginally significant difference in interruption recovery time between the military and non-military participants. As outlined in Table 3, this difference in military and non-military recovery times appears to account for much of the interaction effect between assistance type and decision difficulty. Participants, particularly those with military experience, tended to recover much slower when provided assistance, especially when faced with a complex decision. However, regardless of assistance type, non-military participants tended to take a consistent amount of time to resume the primary task.

Contrary to hypothesis 1, these results indicate that that IRA tool did not minimize participants' recovery time. In fact, when faced with a complex decision after an interruption, the presence of the IRA tool tended to resulted in slower recovery times. This finding is not particularly surprising given that the use of an external decision aid can be time consuming compared to a mental assessment of a situation (Scott, Mercier et al. 2006). However, an interruption recovery tool that increases task resumption time may still be effective, as long as the additional time required to use the tool is not excessive and the tool provides sufficient benefits to other aspects of interruption recovery or overall task performance. As shown in Table 3, there was only a 1.25s increase in mean recovery time for non-military participants who were provided assistance compared to those who were not. However, military participants with assistance took, on average, 25s longer to recovery than military participants without assistance. In extremely time-critical task environments, this 25s difference may be considered excessive, especially if interruptions are frequent, which is often the case for team supervisors. Thus, the additional time could quickly accumulative over the duration of several hours.

With regards to decision accuracy, the results did not indicate a significant difference between assistance types. However, the data are still consistent with hypothesis 2, which predicted that the IRA tool would improve decision accuracy. As illustrated in Figures 23 and 24, the data show a trend for participants with the IRA tool to have better decision accuracy. This trend is particularly apparent for non-military participants, who became as accurate as their military counterparts when provided with assistance. There was also a trend where the use of IRA resulted in improved decision accuracy for participants of either background when faced with a complex decision.

Even though the results of the statistical analysis of interruption recovery performance are inconclusive, the IRA tool appeared to add slightly to the time aspect of interruption recovery performance, while providing some benefits for the decision-making accuracy aspect. The qualitative data analysis presented in Section 5.5 below discusses which aspects of the IRA tool may have contributed to these mixed results. Also, the varied impact of the IRA tool across the military and non-military populations warrants further investigation to provide further insight into the effects of the IRA tool on supervisory-level interruption recovery in different task domains.

5.4.2 Overall Task Performance

Overall task performance refers to how well participants were able to complete the primary task activities to arrive at a successful mission outcome. In our experimental task environment, the convoy health score, which was influenced by how many attacks the convoy sustained and how often the convoy was held stationary during the mission, was used as the measure of overall task performance. The results did not indicate any statistically significant difference in convoy health scores across assistance types. Thus, the results do not provide any evidence in support of hypothesis 3, which predicted that the IRA tool would help increase participants' overall task performance. The consistency in participants' convoy heath scores likely resulted from the task scenario being too simplistic and, thus, not requiring enough cognitively demanding decisions, which would increase the potential for task errors and elicit a greater variety in possible convoy health scores between participants. Thus, the use of the IRA tool in more complex task scenarios warrants further investigation.

5.5 Qualitative Results

The qualitative data obtained from post-experiment interviews and observational information collected provide further insight into the impact and utility of the IRA tool in the experimental task environment. The following sections discuss the participants' interruption recovery strategies, in relation to both the use of the IRA tool and in general, and the overall usability of the IRA tool.

5.5.1 Interruption Recovery Strategies

As reported in the performance results above, with few exceptions, the presence of the IRA tool did not have a statistically significant impact on participants' interruption recovery performance. These results are not particularly surprising in light of the qualitative data also collected. The majority of participants who were provided the IRA tool reported that they rarely or never used this tool. This is also supported by the log file data which shows that only two people (one military and one non-military) interacted with the IRA timeline. Furthermore, both participants limited their interactions to replaying the Late Strike events (as described in Section 3.5), requesting 4 and 6 replay events respectively. The Late Strike event replay was likely used because the strike schedule on the Map Display could become quite cluttered with targets and threat envelopes, making it difficult to recognize any newly scheduled targets during task resumption. While no participant explicitly reported relying on the visualization provided by the IRA timeline, this does not necessarily imply that the participant did not look at the IRA or use it in a non-interactive way. The fact that military participants tended to take longer to recover when faced with complex decisions suggests they may have been visually examining the IRA timeline to investigate the situation.

However, even when the IRA tool was available, it was not heavily used to aid participant interruptions recovery in the primary task. Only one participant reported using the IRA tool for interruption recovery. Two alternative interruption recovery strategies were revealed by the post-experiment interviews, neither of which involved the use of the IRA tool, even when it was available. The first strategy, reported by five of the twelve participants, involved relying on their memory of the situation, in particular of the status of the map, and comparing the post-interruption situation to their mental image of the pre-interruption state. Using the visual memory system to observe differences in mission status is a very ineffective form of recovery as humans are very susceptible to change blindness (Section 2.2). This strategy would be particularly ineffective after a long interruption as the memory of the map would likely fade over time.

The second strategy, reported by the remaining six participants, involved a combination of the first strategy in addition to mentally noting the time when the interruption occurred to be used to later check for any new status messages on either the Mission Commander Interface or Mission Status Display that appeared during the interruption time. This method has the advantage of being comprehensive if the message history records all events that occur, but it can also introduce lengthy recovery times by requiring users to read many, possibly irrelevant, messages. This method is also susceptible to memory fade during longer interruptions or the lack of initial time reference if the team supervisor does not have the opportunity to check the time before an interruption. This method can also be cognitively demanding as textual descriptions corresponding to spatial events must be mentally translated to on-screen map events, and could delay decision making.

It is interesting that even though the experimenter encouraged the use of the IRA tool during the practice sessions and emphasized that the purpose of the IRA tool was to assist in recovery from interruption, most participants did not incorporate the IRA tool into their recovery process. One possible explanation for this finding is that the task scenario may not have been challenging enough, as discussed in Section 5.4.2. The fact that all participants made the optimal decision when faced with a simple decision, and that there was little variation in convoy health scores indicate that there may not have been enough critical events during the mission to require the use of an interruption recovery tool. Theoretically, the best overall task performance score (i.e., convoy health) a participant could achieve in the experimental task scenario was 94/100. As Table 5 indicates, the mean convoy health score was close to this optimal score (M=89.9, SD=3.6). This finding suggests that further investigations should incorporate more challenging task scenarios. It is also possible that the participants did not receive sufficient training to acclimate to the use of the IRA tool during interruption recovery.

These findings indicate that few participants used the IRA tool, either for the visual summary provided by the IRA timeline or for its event replay capabilities. The following section discusses several usability issues revealed by the post-experiment interviews related to the visual and interaction design of the IRA tool that likely contributed to participants' limited use of the IRA tool.

5.5.2 Usability Issues with IRA

In the two practice sessions, participants were introduced to all functionalities of each interface. The goal of the practice sessions was to be entirely comprehensive in order to cover all functions of the task environment and allow the participants to develop their own strategies without bias. However, participants with the IRA tool were explicitly told that this tool was designed to assist in interruption recovery, and would also be helpful as a general decision support tool in displaying key events. Contrary to these instructions, it seemed that the participants developed their own interruption recovery and general information acquisition strategies.

Participant interview comments revealed that most people felt the IRA tool did not provide information that was not already available on the large screen displays in some form. Thus, they did not see the value in using it for interruption recovery or for performing the task in general. However, the IRA timeline visualization was specifically designed to provide information that was, for the most part, already available on the large screen displays, but in a more readily accessible, comprehensible form. Its purpose was to provide a visual summary of events that enable the mission commander to look to one place in the interface to quickly understand the current state of the system, and to become informed of any relevant past events. Thus, it was intended that the information be more easily gathered from a central display, the IRA timeline, which also enabled more detailed investigation through the IRA event replay capabilities. However, the interviews revealed that participants preferred to look at the large screen displays to gather event information. It is possible that the large (42") plasma displays were so visually salient and compelling, as compared to the small (14") tablet PC display that this interfered with the potential usefulness of the information provided on the respective displays.

Participants consistently reported that the IRA listing of "UAV Destroyed" events was redundant since this information was more salient on the large screen displays. This result is not particularly surprising since, as discussed in Section 3.2.1, the awareness information provided on the existing UAV team task interfaces was identified as a feature that may satisfy some of the interruption recovery requirements derived from the cognitive task analysis. This result suggests that system designers should carefully investigate whether information necessary for interruption recovery is currently provided on an existing task displays in a form that can be easily and quickly understood before augmenting a decision support display with additional summary information.

However, the interview results in conjunction with the computer log files indicate that not all information on the large screen displays was sufficient to assist interruption recovery. One type of event that was displayed on the IRA event timeline was status changes of the communication links. Participants consistently reported that this IRA event information was redundant since it could be easily obtained from the communications links panel on the Mission Status Display. Yet, three out of six participants who performed the study with the IRA tool attempted to request surveillance data from JSTARS after Interruption 2, even though the JSTARS communication link had been lost during the interruption, and was still down during task resumption. Two of these three participants were the only people to use the event replay capabilities of the IRA tool, which they both did several times prior to their failed request for JSTARS data. It appears, then, that communication link status information is not being conveyed effectively, on either the IRA timeline or on the Mission Status Display. This information needs to be more salient in order for the team supervisor to better understand the current situation during interruption recovery.

Another usability issue that participants reported was that IRA timeline events did not correspond directly to the decisions participants were faced with following the experimental interruptions. For example, participants found the "Convoy Attack" events irrelevant because they did not help participants with any specific decisions after an interruption. The original intention of including Convoy Attack events in the IRA tool was to help mission commanders notice when the convoy entered a target threat range. However, since the convoy health only decreases once when it comes within range of a target, there was no incentive for the mission commander to hold the convoy if it has already been attacked by a particular target. So while knowing the convoy was attacked was important to help participants stay apprised of their current mission performance, which in general was useful for setting priorities of decisions and making risk tradeoffs, this information was not directly related to any particular decision.

A critical finding from the post-experiment interviews was related to the overall design of the IRA tool, and particular, the design decision to locate the IRA timeline on the Mission Commander Interface on the tablet PC display. Participants found it annoying and distracting to have to look down at the tablet PC and then back to the large screen displays throughout the UAV team task. Several people recommended that, in order to keep all interfaces on the same viewing plane, the IRA timeline along with the other decision controls be integrated directly into the large screen interfaces.

Recall that the design goals for the IRA tool discussed in Section 3.2 were to provide the mission commander with an interruption recovery tool that provides an integrated visual summary of decision relevant events in the form of an event timeline that enables replay of past events. The IRA tool provides integrated replay of past events through the highlighting of past events directly on the Map Display, as outlined in Section 3.5. However, the fact that the visual summary and control input to the replay of events, the IRA timeline, are located on the Mission Commander Interface (as opposed to the Map Display), may have significantly diminished its usefulness as an interruption recovery tool. Experimenter observations during the study helped to elucidate this issue, which are discussed in the next section.

Observations revealed that participants' interactions with the Map Display resembled a primary task, and their use of the other displays in the task environment was analogous to an interruption. Participants typically focused on the Map Display, and when a system component's state changed, the participant looked at the corresponding peripheral display (Mission Commander Interface, Mission Status, or Remote Assistance Displays) to gain additional information or to execute a command decision. Thus, it appears that for an interruption recovery tool to be "integrated" into this particular task environment, the visual summary, and likely control of any replay capabilities, should be integrated into the Map Display. This display already contains a prominent visual timeline, the Convoy Threat Summary and Strike Schedule, which participants found extremely useful for performing the UAV team task. The fact that the IRA "Late Strike" event replay currently involves visually updating the Strike Schedule timeline suggests that integrating these two times may be feasible. This integration has the advantages of the proximity of the IRA component to the main display components. In addition, since the wall displays provide a potential resource for the entire UAV team, the IRA tool would then be available to other team members. On the other hand, integrating the IRA timeline into the wall displays may introduce visual clutter, potentially interfering with the usability of the existing information provided by these displays.

5.6 Summary

The statistical analysis of the study data produced mixed results regarding the effectiveness of the IRA tool for supervisory-level interruption recovery in a complex team environment. Though the IRA tool tended to negatively impact recovery time, especially in complex task situations, it also tended to positively impact decision accuracy, again especially in complex task situations. The results also indicate that the effect of the IRA tool tended to differ across different user populations. The IRA tool tended to have a more positive effect on decision accuracy and less of a negative impact on recovery time among non-military participants. Since the power of the analysis was limited by the population size, a larger study is needed to confirm these trends. Additionally, the results indicated that using a more challenging task scenario may help elicit a larger variation in performance scores, which might help clarify the impact of the IRA tool on overall task performance.

The qualitative observations add insight to the quantitative results, in that they highlight possible usability issues and provide several ideas for future extensions and improvements to the IRA tool. Specifically, the post-experiment interviews and log files indicate that integrating the IRA tool into the large-screen displays may increase its effectiveness. It is possible, though, that participants' preference for large-screen displays may be a saliency issue rather than a usability one. Further investigation is needed to address this issue.

The following chapter discusses the conclusions that can be drawn from the results presented in this chapter, summarizes the contributions made in this thesis, and proposes future extensions and improvements to the IRA tool.

Chapter 6: Conclusion

This thesis presents the design and initial investigation of an interactive interruption recovery tool in time sensitive, collaborative human supervisory control task environment typical to many mission control operations. This research extends previous work by Scott et al. (2006) and St. John et al. (2005) to the domain of responsibility for team supervisors, rather than individual operators in a human supervisory control task environment. The challenges of team supervision in this domain are compounded by the need to supervise and collaborate with both intelligent systems and human operators. This chapter summarizes the findings of this research in the context of the initial research objectives of the thesis, and discusses future research directions suggested from the results of this work.

6.1 Research Objectives and Findings

The objectives of this research were to investigate the interruption recovery requirements for team supervisors in complex, collaborative human supervisory control task environments, to develop an interruption recovery assistance tool, and to evaluate the effectiveness of the assistance tool. This aim of this thesis was to address these objectives with the following methods:

- Conduct a cognitive task analysis and literature review to develop interruption recovery requirements for assisting team supervision in a representative complex human supervisory control team task environment (Chapter 3).
- Design an interruption recovery assistance tool that addresses the interruption recovery requirements (Chapter 3).

- Perform a user study to evaluate the effectiveness of the new interruption recovery assistance tool in a complex collaborative human supervisory control environment (Chapters 4 and 5)

The interruption recovery requirements analysis led to the design and implementation of an interruption recovery assistance (IRA) tool for an existing complex human supervisory team task environment. The IRA tool provides mission commanders of an unmanned aerial vehicle operations team with a visual summary of the past events on an interactive event timeline. The IRA tool enables mission commanders to replay past system events directly in the primary task display, which contains the situation map display along with visualizations of other mission and team awareness information.

The evaluation of the IRA tool produced mixed results regarding the effectiveness of the IRA tool for supervisory-level interruption recovery in a complex human supervisory control team environment. The statistical analysis indicated that the IRA tool can negatively impact recovery time while positively impacting decision accuracy, especially in complex task situations. The study results also indicated that the effect of the IRA tool can differ across user populations. In the user study, the IRA tool tended to more positively impact the interruption recovery performance of participants without military experience. However, a larger population sample is needed to confirm the generalization of the findings from the quantitative data analysis.

The findings from the qualitative data analysis performed on the post-experiment interview data and experimenter observations provided further insight into the impact and utility of the IRA tool. These findings indicated that few participants made use of the IRA tool as part of the interruption recovery process, particularly its event replay capabilities. The findings also revealed several usability issues related to the visual and interaction design of the IRA tool that likely contributed to this limited use of the IRA tool. In particular, the findings indicated that the location of the IRA event timeline on a portable, tablet PC display, which also provided functionality for implementing command decisions in the task environment, inhibited its perceived utility as participants found it distracting to look between this display and the primary task interface, located on a set of large-screen wall displays.

6.2 Recommendations and Future Work

Given the inconclusive results of this thesis, further work is warranted to clarify the effectiveness of the IRA tool, and potentially other design approaches to interruption recovery assistance for team supervisors in complex human supervisory control tasks such as mission control operations. The following are recommendations for future research directions based on the research presented in this thesis.

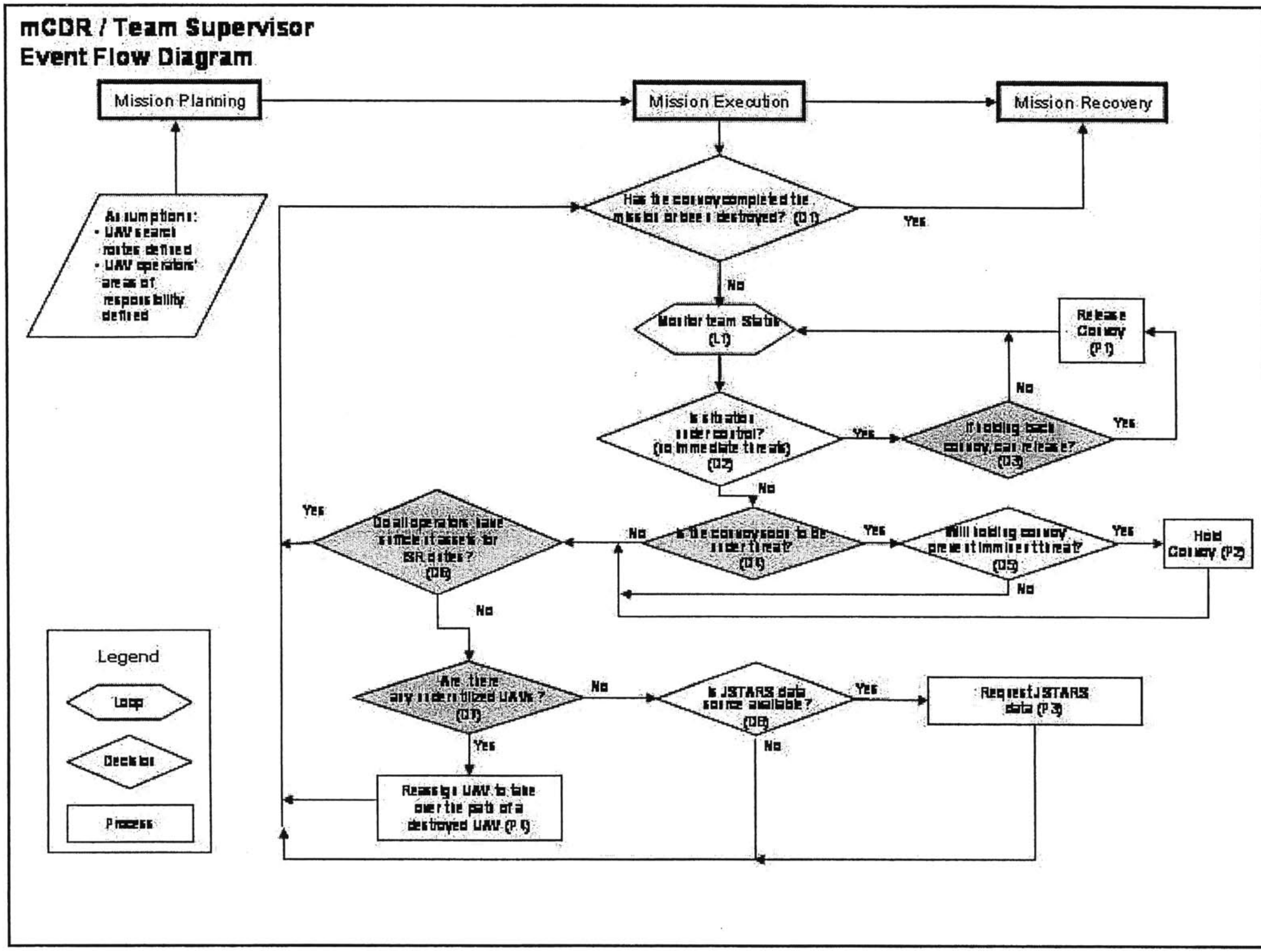
The study results indicated that the task scenarios were overly simplistic and the interruptions likely too short to produce significant differences in interruption recovery or overall task performance. Including more challenging task scenarios and interruptions of longer and varied durations in future experiments may help clarify the utility of the IRA tool.

Usability issues revealed by the user study indicated that the design of the IRA timeline should be updated to improve the saliency and comprehensibility of bookmarked events, as well as to include only system events that are directly relevant for supervisory-level decision making in the task environment.

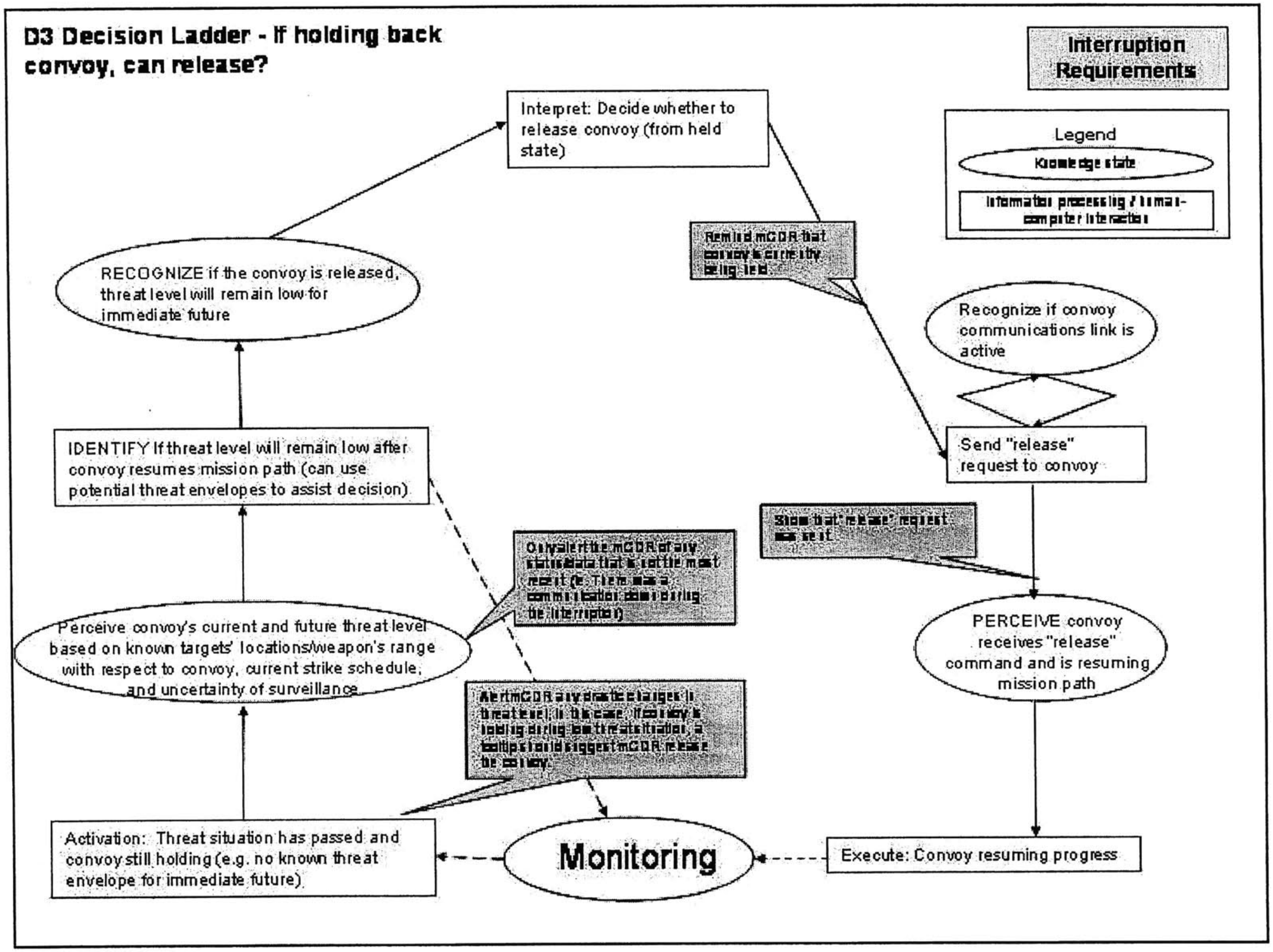
The results indicated that integration of the IRA event timeline into the large-screen wall displays, which serve as the primary task displays in the experimental task environment, may help minimize the distraction associated with using the IRA tool during task resumption.

Finally, in light of the lack of evidence from the study to support utility of the event replay capabilities of the IRA tool, it may be appropriate to reconsider the need for event replay for team supervisors in complex human supervisory control environments.

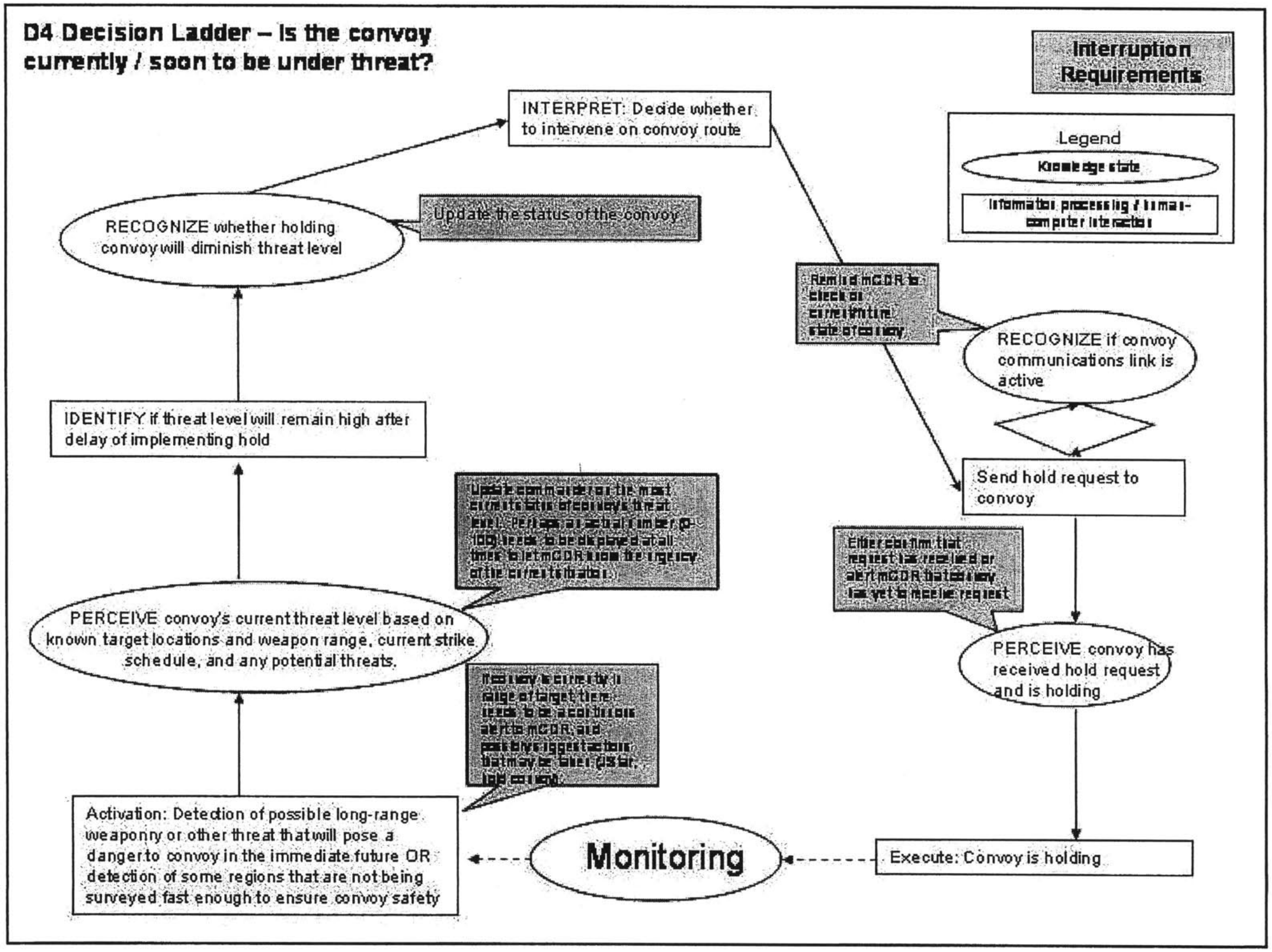
Appendix A: Detailed Diagrams from Cognitive Task Analysis



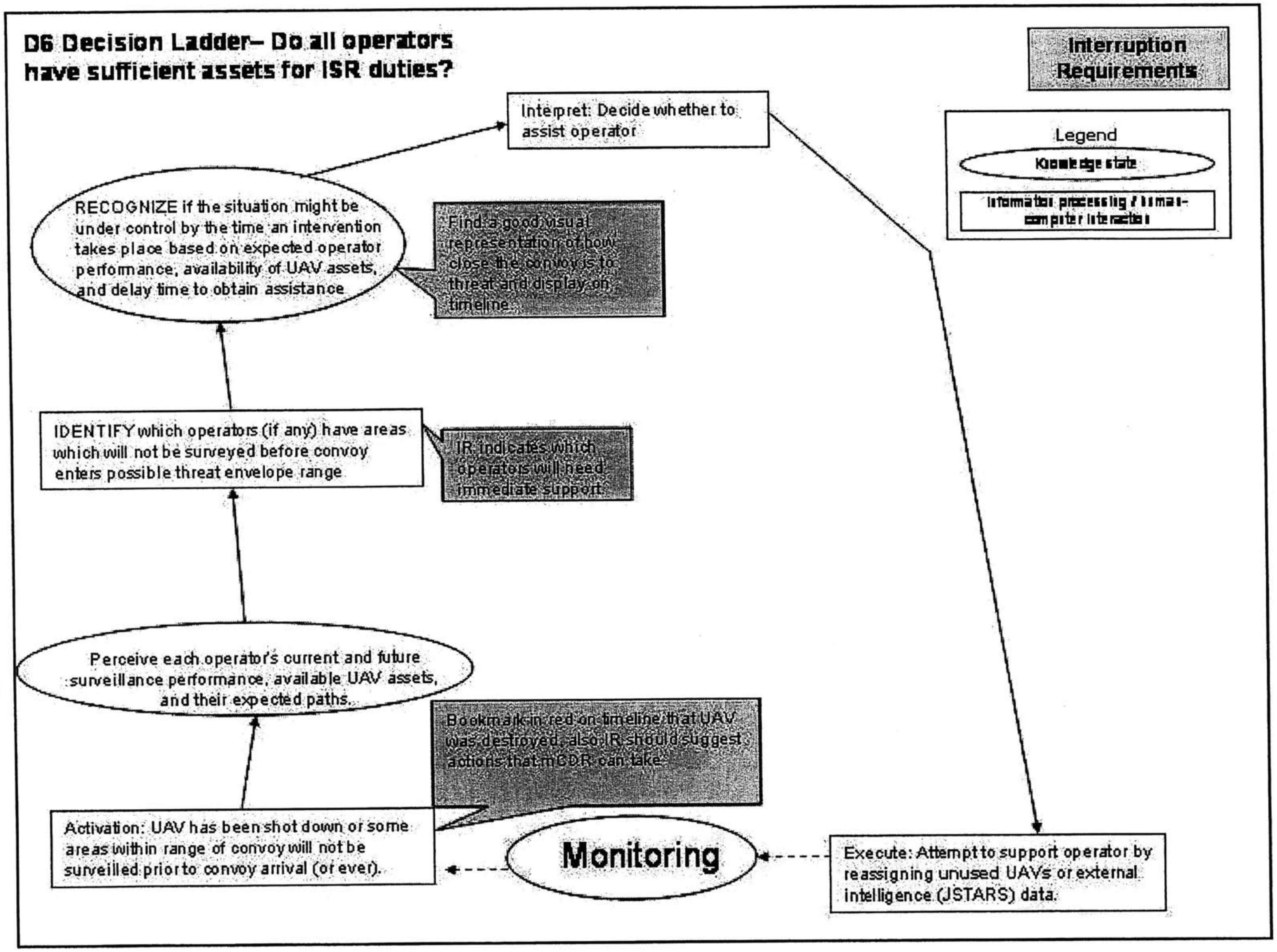
Enlarged Image Corresponding to Figure 11



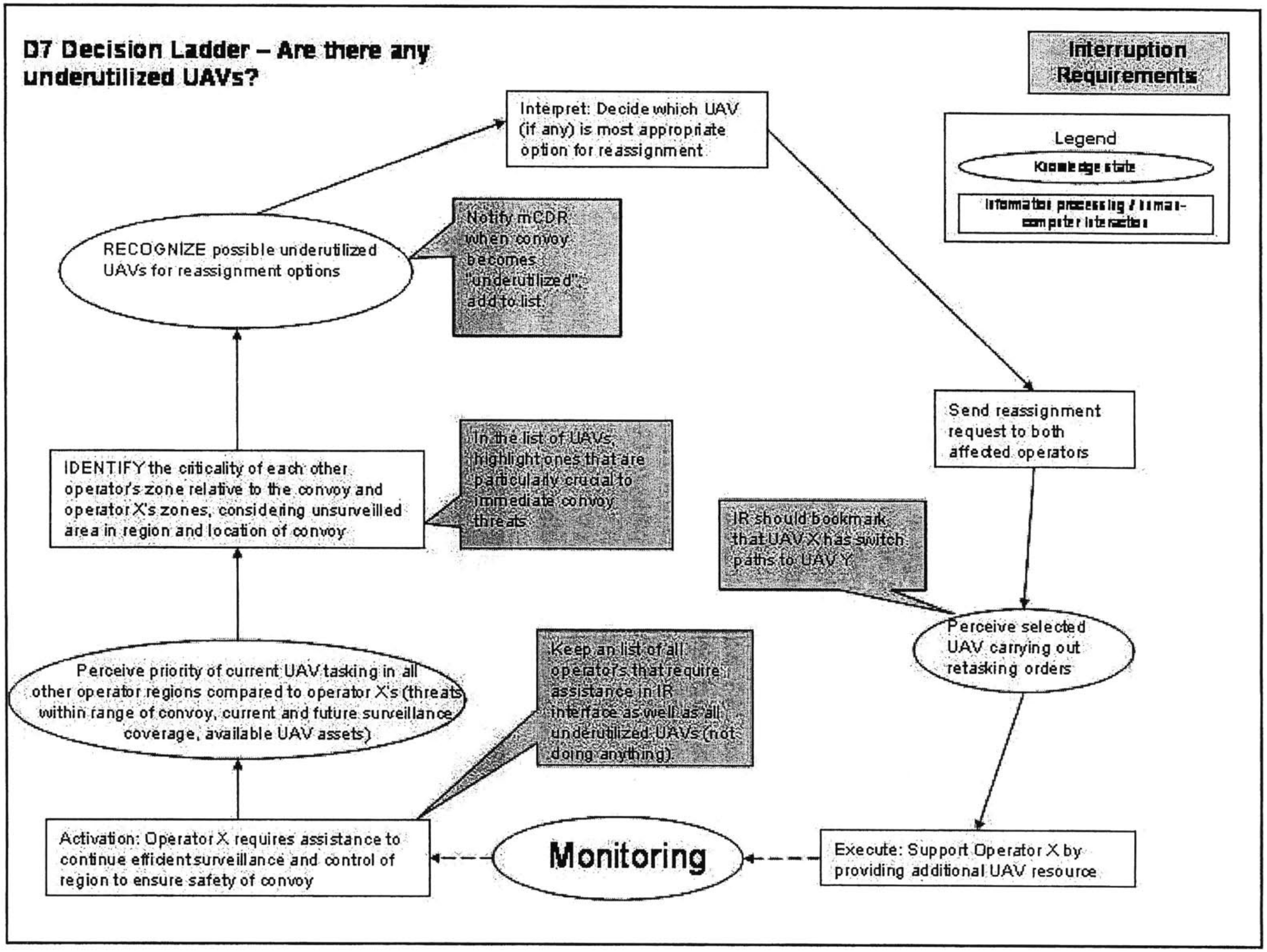
Enlarged Image Corresponding to Figure 10



Enlarged Image Corresponding to Figure 12



Enlarged Image Corresponding to Figure 13



Enlarged Image Corresponding to Figure 14

Appendix B: Interruption Recovery Requirements

1. Remind mCDR that convoy is currently being held.
2. Show that "release" request was sent.
3. Notify mCDR of any communication status changes during interruption.
4. Alert mCDR of drastic changes in threat level, suggest convoy actions.
5. Remind mCDR to check on current/future state of convoy
6. Update the status of the convoy
7. Update the status of Hold/Release Convoy request.
8. If convoy is in range of target, suggest actions to take (ex. JSTAR).
9. Update mCDR on current status of convoy's threat level.
10. Notify when UAV was destroyed, and suggest actions that mCDR can take.
11. IR indicates which operators will need immediate support.
12. Display how close the convoy is to a threat and also display on timeline.
13. Notify that UAV X has switch paths to UAV Y.
14. Display list of all operator's that require assistance.
15. Display list of underutilized UAVs (not doing anything).
16. Highlight UAVs that are particularly crucial to immediate convoy threats

Requirements	Currently Supported by
Remind mCDR that convoy is currently being held.	Spatial Map (MD)
Show that "release" request was sent.	Message History (MSD, MCI)
Notify mCDR of any communication status changes during interruption.	Not Supported
Alert mCDR of drastic changes in threat level, suggest convoy actions.	Not Supported
Remind mCDR to check on current/future state of convoy	Not Supported
Update the status of the convoy	Spatial Map (MD)
Update the status of Hold/Release Convoy request.	Not Supported
If convoy is in range of target, suggest actions to take (ex. JSTAR).	Not Supported
Update mCDR on current status of convoy's threat level.	Not Supported
Notify when UAV was destroyed, and suggest actions that mCDR can take.	Not Supported
IR indicates which operators will need immediate support.	Operator Performance Panel (MSD)
Display how close the convoy is to a threat and also display on timeline.	Spatial Map, Convoy Threat Summary (MD)
Notify that UAV X has switch paths to UAV Y.	Not Supported
Display list of all operator's that require assistance.	Not Supported
Display list of underutilized UAVs (not doing anything).	Not Supported

Appendix C: Demographic Data

Note: the numbers listed under Occupation correspond to the student's major of study, found in the legend below the table.

Subject	Age	Gender	Occupation	Military	Experience	Video-games	Color-blind
1	22	Male	Undergrad/18	None	No	0-1hr	No
2	19	Male	Undergrad/17	AF, 1.5	Yes	0-1hr	No
3	23	Male	RA	None	Yes	1-4hrs	No
4	23	Male	Lab Tech	None	No	0-1hr	Yes*
5	22	Male	Undergrad/2	None	Yes	1-4hrs	No
6	20	Male	Undergrad/18	AF, 1.5	Yes	1-4hrs	No
7	21	Male	Undergrad/18&6	None	No	1-4hrs	No
8	19	Male	Undergrad /6	None	No	1-4hrs	No
9	20	Female	Undergrad /16	AF, 1.5	Yes	1-4hrs	No
10	20	Male	Undergrad /16	AF, 1.5	Yes	0-1hr	No
11	21	Female	Undergrad /22	None	No	Never	No
12	18	Male	Undergrad /NA	AF, 1.5	No	1-4hrs	No
13	20	Male	Undergrad /17	Army 1.5	No	1-4hrs	No

*red/green/brown colorblindness

Undergraduate Majors
18 = Mathematics
17 = Political Science
2 = Civil Engineering
6 = EECS
22 = Nuclear Engineering
16 = Aeronautical Engineering

Other Abbreviations:
R A = Research Assistance
AF = Air Force
NA = no declared major

Appendix D: Interruptions

Interruption 1

1. Please order today's temperatures of these city from smallest to greatest (approximate).

   A. Miami, Florida:
   B. Anchorage, Alaska:
   C. Boston, Massachusetts:
   D. Indianapolis, Indiana:

2. What is the best deal?

   A. four apples for $4
   B. seven apples for $8
   C. nine apples for $10

3. Give me your one word description of the war on Iraq?

IF YOU ARE DONE, PLEASE REMAIN SEATED UNTIL THE INTERRUPTION IS FINISHED. THANKS!

DON'T FORGET TO FILL OUT THE INCIDENT REPORT AT YOUR EARLIEST CONVIENANCE WHEN YOU RETURN TO THE MISSION CONTROL ROOM. THE REPORT IS MANDATORY FOR EACH INTERRUPTION THAT OCCURS.

Do not write below

Subject ID:
Mission Time:
Condition:

Interruption 2

Assumptions:

Jack is Taller than Tom

Tom is Taller than Steve

Steve is shorter than John

True/False Questions:

1. Jack is taller than Steve.[T/F].

2. John is the shortest. [T/F].

3. From these assumptions, We cannot infer whether John is Taller than Jack [T/F].

4. (freebie) You found these questions confusing [T/F].

IF YOU ARE DONE, PLEASE REMAIN SEATED UNTIL THE INTERRUPTION IS FINISHED. THANKS!

DON'T FORGET TO FILL OUT THE INCIDENT REPORT AT YOUR EARLIEST CONVIENANCE WHEN YOU RETURN TO THE MISSION CONTROL ROOM. THE REPORT IS MANDATORY FOR EACH INTERRUPTION THAT OCCURS.

Do not write below

Subject ID:
Mission Time:
Condition:

Interruption 3

Glenn: Space station getting shortchanged
Source: www.cnn.com

COLUMBUS, Ohio (AP) -- The country is not getting its money's worth out of the international space station, John Glenn said Tuesday, the 45th anniversary of the day he became the first American to orbit the Earth.

Diverting money from the orbiting research outpost to President Bush's goal of sending astronauts back to the moon and eventually on to Mars is preventing some scientific experiments on the space station, Glenn told an audience of about 300 high school students and space enthusiasts at the COSI Columbus science center.

Glenn made three trips around the planet inside his Friendship 7 capsule on February 20, 1962, making him a national hero and proving that the nascent NASA space program was competitive with the Soviet Union, which had accomplished a manned orbital flight a year earlier.

He said he supports the president's moon and Mars goals but not at the expense of the space station, which is only two-thirds complete.

Question

What do you think is the motivation behind President Bush's diversion of funds from the space center to sending astronauts back to the moon?

IF YOU ARE DONE, PLEASE REMAIN SEATED UNTIL THE INTERRUPTION IS FINISHED. THANKS!

DON'T FORGET TO FILL OUT THE INCIDENT REPORT AT YOUR EARLIEST CONVIENANCE WHEN YOU RETURN TO THE MISSION CONTROL ROOM. THE REPORT IS MANDATORY FOR EACH INTERRUPTION THAT OCCURS.

Do not write below

Subject ID:
Mission Time:
Condition:

Appendix E: Incidence Report

During the experimental trail, participants were given three sheets of incident report to write down any observed changes to the task environment while they were interrupted.

Incidence Report

Current Time:

<u>Changes to mission status:</u>

Appendix F: Informed Consent

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 Mary Cummings Ph.D, from the Aeronautics and Astronautics Department at the Massachusetts Institute of Technology (M.I.T.). You were selected as a possible participant in this study because the expected population this research will influence is expected to contain men and women between the ages of 18 and 50 with an interest in using computers. 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 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 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:

- Attend a 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 experimenter 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 $10/hr 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 postdoctoral investigator is Stacey D. Scott and she may be contacted by telephone at (617) 228-5046 or via email at sdscott@mit.edu.

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.

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.

	Please Circle One		Please Initial Your Choice
I agree to participate in the activities explained above	**YES**	**NO**	____
I agree to be videotaped, photographed, and audiotaped	**YES**	**NO**	____
I agree to let the videotapes/photographs/audiotapes be used for presentation of the research results	**YES**	**NO**	____

____

Name of Subject

______________________________ ____________

Signature of Subject 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 G: Demographics

Collaborative TST Demographic Survey

1. **Age:** ____________________

2. **Gender:** □ Male □ Female

3. **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:* ____________________

4. **Do you have experience with remotely piloted vehicles (land, sea, air)?**
   □ Yes
   □ No

   If yes:
   a. *Vehicle type(s)/class(es):*
   ____
   b. *Number of hours:* ____________________

5. **Do you have experience supervising a team of operators piloting vehicles (land, sea, air)?**
   □ Yes
   □ No

   If yes:
   a. *Vehicle type(s)/class(es):*
   ____
   b. *Responsibilities as team supervisor:*
   ____
   c. *Size of teams:* ____________________
   d. *Number of hours:* ____________________

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

□ Yes
□ No

If yes:

a. *Types of time-critical situations:*
____

b. *Responsibilities as team supervisor:*
____

c. *Size of teams:* ____________________

d. *Number of hours:* ____________________

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

□ Yes
□ No

If yes:

a. *Types of non time-critical situations:*
____

b. *Responsibilities as team supervisor:*
____

c. *Size of teams:* ____________________

d. *Number of hours:* ____________________

8. 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

9. Are you color blind?

□ Yes
□ No

If yes:

Which type of color blindness (if known)_______________________________________

Appendix H: PowerPoint Tutorial

Assisting in Collaborative Time-Sensitive Targeting

MIT Humans & Automation Lab

Experimenter: Stacey Scott & Jordan Wan

Principal Investigator: M.L. Cummings

Spring 2007

Training Overview

There will be 3 phases of your participant training:

1. Mission Summary & Mission Goals
2. Introduction of the Experiment Displays
3. Practice Sessions

Mission Summary

In this experiment, you will be in command of a team of unmanned aerial vehicle (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.

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).

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 JSTARS (Joint Surveillance & Target Attack Radar System), a local multi-sensor aircraft, to supplement your team of UAVs.

During the mission, interruptions may occur which will simulate realistic military environments in which a mission commander may be required to

Mission Goals

The primary goals of this mission are to get the convoy through your AOI as quickly as possible, as safely as possible. Therefore, **clearing a threat-free path** for the convoy and **keeping the convoy moving** are your team's highest priorities.

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 all the roads in the area for safe passage of future convoys. The second will be to assist remote operators in target classification.

Finally, as the mission commander, another priority of yours will be to monitor the performance of the strike team and to

Possible Command Interventions

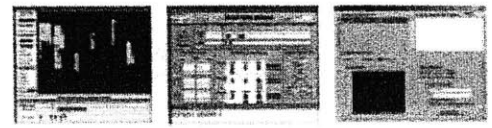
In order to achieve your mission objectives you will have three types of commands at your disposal:

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 (you may only do this once for each UAV).

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

Experiment Displays: TST Supervisor Displays

Large-Screen Wall Displays



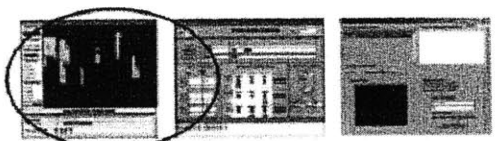
Map Display | Mission Status Display | Remote Assistance Display

Tablet PC Display

Mission Commander Display

Map Display

Large-Screen Wall Displays



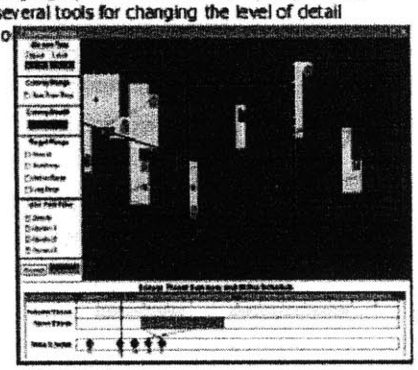
Map Display | Mission Status Display | Remote Assistance Display

Tablet PC Display

Mission Commander Display

Situation Map Display (cont'd)

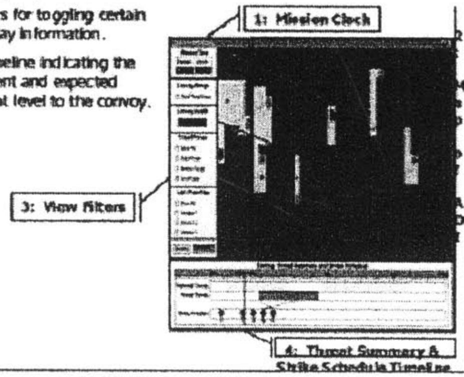
The **situation map display** visualizes positional information of relevant contacts and assets in the context of your team's geographical area of interest (AOI). It also provides several tools for changing the level of detail displayed o



Situation Map Display (cont'd)

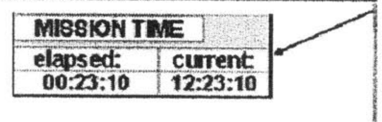
The main components of this display, described in detail next, are:

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.



Situation Map Display

(1) Mission Clock



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

Situation Map Display

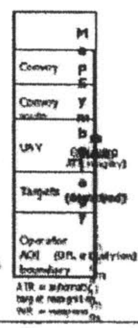
(2) Map: Geospatial Mission Activity

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. If a UAV is lost (i.e., goes down for any reason), it is grayed out at its last known location.



Situation Map Display

(3) View Filters

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 (with your finger or the wall pen) inside the check box. A checkmark will appear in the box and the corresponding information will appear on the map.

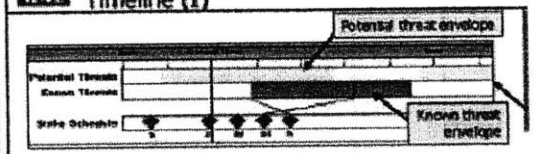
To **hide** the information, touch inside the checkbox again. The checkmark and corresponding map information will disappear.

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 highlight and 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.

Situation Map Display

(4) Threat Summary & Strike Schedule Timeline (I)



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.

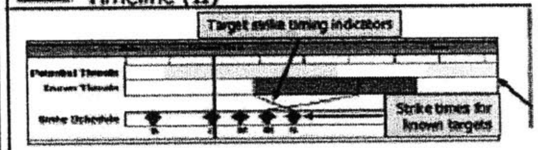
Yellow/potential threat envelopes correspond to periods of time when the convoy will be within expected weapons **range of an unsurveilled area,** which may contain a target.

Each time the convoy enters a threat envelop (i.e., comes within weapons range

(continued on next slide...)

Situation Map Display

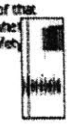
(4) Threat Summary & Strike Schedule Timeline (II)



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.

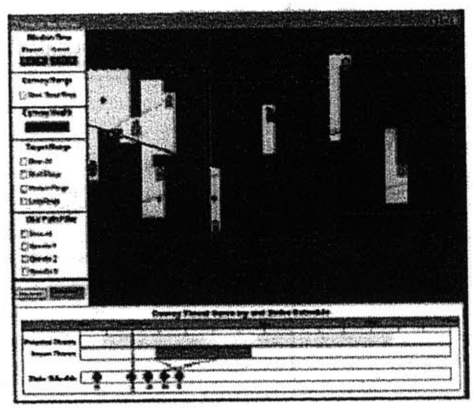
The target ID is provided below each target as a alphanumeric tag indicating the target number and its weapons range capability (S=short, M=medium, L=long). The target's position on the strike schedule represents the expected time the strike team will destroy the target.

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 whe[ther] 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 13S & 14S in the schedule to the right will be destroyed before they can harm the convoy. However,

Any Questions?

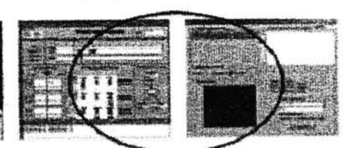


Advance slide when you are ready...

Mission Status Display

Large-Screen Wall Displays

Map Display



Mission Status Display

Remote Assistance Display

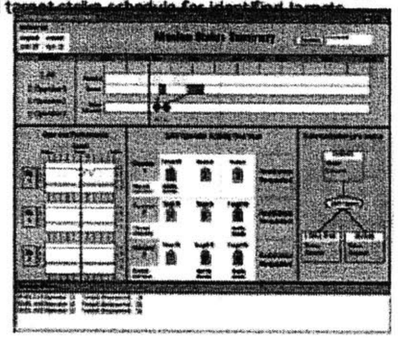
TabletPC Display

Mission Commander Display

93

Mission Status Display

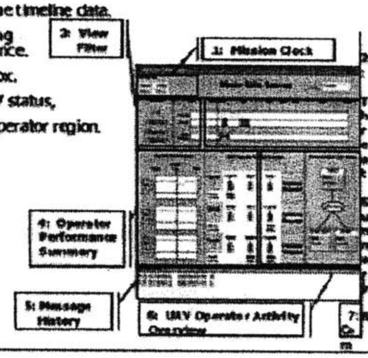
The **Mission Status Display** visualizes current and expected mission status information, which includes surveillance progress for each UAV operator and given areas of interest, communications link status to external resources, and expected t



Mission Status Display

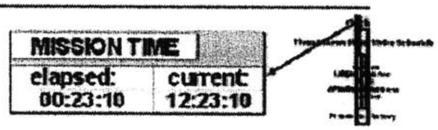
The main components of this display, described in detail next, are:

1. The mission clock.
2. Timeline summarizing current and expected convoy threats & the expected time of corresponding target threats.
3. Filter toggles for the timeline data.
4. Graphs summarizing operator performance.
5. Message history box.
6. Panel showing UAV status, broken down by operator region.
7. Current communication link status.



Mission Status Display

(1) Mission Clock

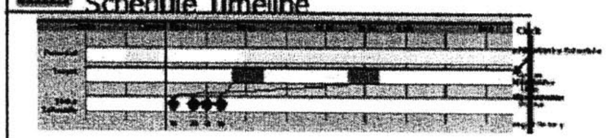


The Mission Clock shows the up-to-date mission times, including the **elapsed time** since the beginning of the test session and the **current mission time**.

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

Mission Status Display

(2) Threat Summary & Strike Schedule Timeline



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

This timeline is a mirror of the one described earlier on the Map Display.

Mission Status Display

(3) Timeline View Filter

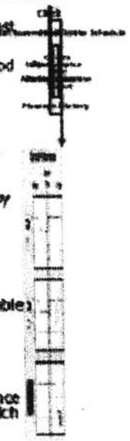
The Timeline View Filter panel provides toggle check boxes to enable you to show or hide target information for all or a subset of the operator regions on the timeline. By default all toggles are set to the 'on' (i.e., 'show') position.

To show target information relating to a particular operator, touch (with your finger or the wall pen) inside the corresponding check box. A checkmark will appear in the box and the threat envelop and target information related to that operator's region will appear on the timeline.

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

Mission Status Display

(4) Operator Performance Summary



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

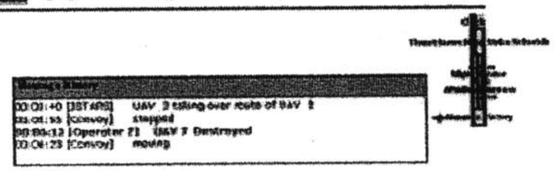
The operator performance level (1-4) reported at each time period is based on the following heuristic:

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

(5) Message History



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.

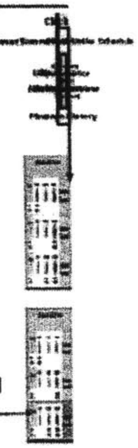
Each message begins with a time-stamp indicating when it was received and a label indicating the message source. Critical system messages are displayed in red.

The contents of this message history are mirrored on the TabletPC Display.

Sample messages will be provided later in the tutorial.

Mission Status Display

(6) UAV Status Activity Overview



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.

Mission Status Display

(7) Communications Link Status

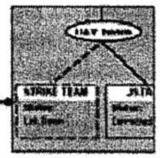
The Communications Link Status panel displays the current status of your UAV team's communication connections to external contacts:

- 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), the communications line is down.

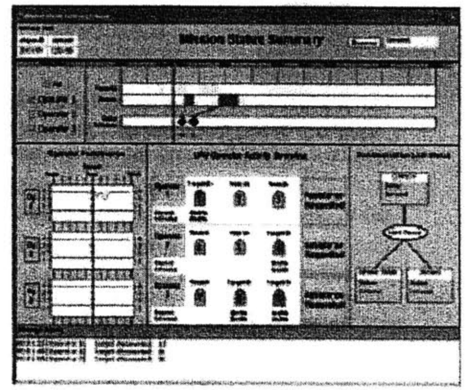
Each box representing the external contacts displays

- Contact name
- Current communication status



Communication between an UAV team and Strike team is down.

Any Questions?

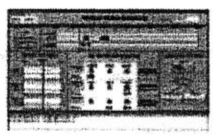


Advance slide when you are ready...

Remote Assistance Display

Large-Screen Wall Displays

Map Display



Mission Status Display

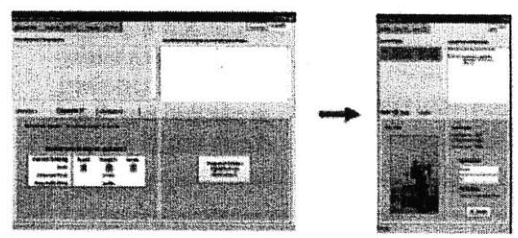
Remote Assistance Display

TabletPC Display

Mission Commander Display

Remote Assistance Display

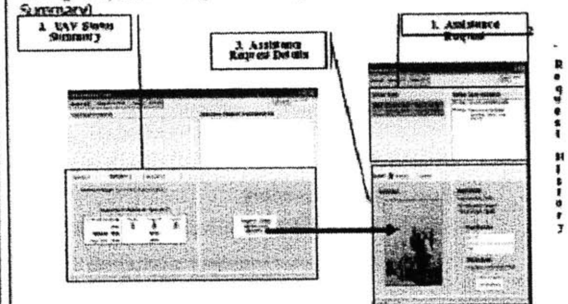
The Remote Assistance Display (RAD) allows the mission commander to **assist the remote UAV operators who are taking too long (>30 seconds) to perform the target identification task.**



Remote Assistance Display

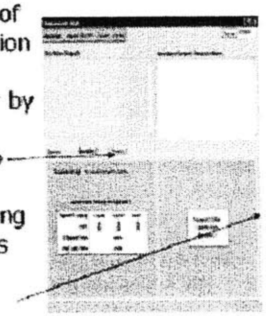
The main components of this display are:

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).



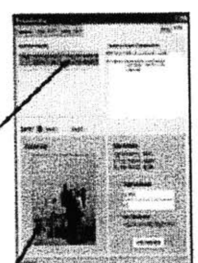
Remote Assistance Display (1) Request Status Update from Operator X

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".



Remote Assistance Display (2) Assistance Request

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.



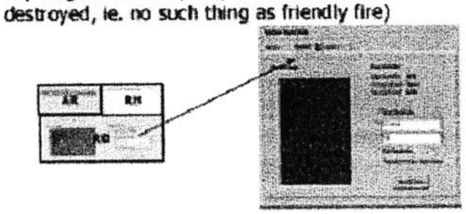
By clicking the request box, the target image details will appear.

Remote Assistance Display (3) Request Details

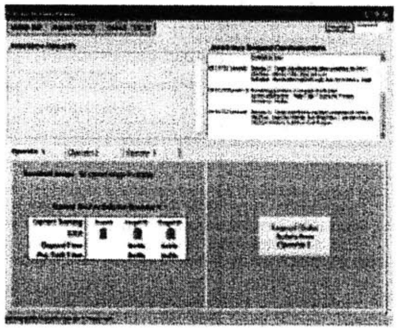
For each assistance request, the details displayed include: UAV, time received, Target Classification, and Target image. It is the responsibility of the mission commander to:

a) To the best of your ability, match the target classification to the image.

b) Veto any non-military targets (you may assume any target with weaponry threat should be destroyed, ie. no such thing as friendly fire)



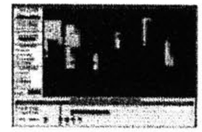
Any Questions?



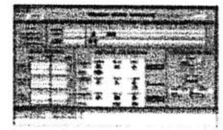
Advance slide when you are ready...

Mission Commander Display

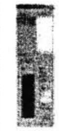
Large-Screen Wall Displays



Map Display



Mission Status Display



Remote Assistance Display

TabletPC Display

Mission Commander Display

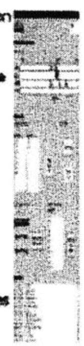
Mission Commander Display

The TST 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 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 (once per UAV).

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.

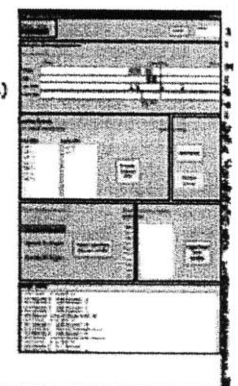


The specifics of this display and the corresponding task functionality will be explained in the following slides.

Mission Commander Display

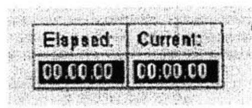
The main components of the TST mission commander decision display, described in detail next, are:

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.
7. Text message box.



Mission Commander Display

(1) Mission Clock

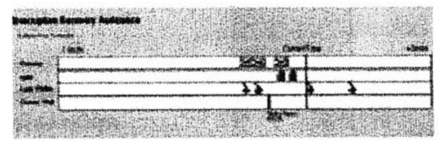


The Mission Clock shows the up-to-date mission times, including the **elapsed time** since the beginning of the test session and the **current mission time**.

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

Mission Commander Display

(2a) IRA - Overview



The IRA (Interruption Recovery Assistance) panel is an interactive panel consisting of a timeline and iconic bookmarks which are clickable by the user. These interactive bookmarks help 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

Mission Commander Display

(2b) IRA – Event Detection Descriptions

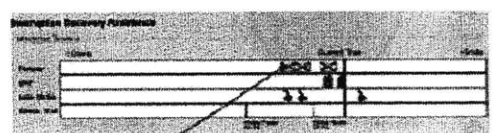
The four events that will be monitored by the IRA tools are listed below.

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.

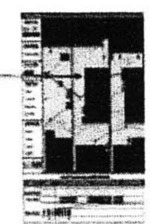
Icon	Event	Triggered By:	Click action:
	Convoy Attacked	Convoy gets attacked	Draw a red X on the spatial map (Situational Map Display) where convoy was hit.
	UAV Destroyed	UAV is destroyed	Draw a maroon box around the destroyed UAV on the spatial map.
	Late Strike	A buffer violation (target will not be eliminated [illegible]	Draw a box around the corresponding target that will not be eliminated on [illegible]
	Communication Status Change	If any of the communication (JSTAR, Convoy, UAV) links changes status (connect/disconnect).	Display red dotted line on IRA timeline if communication was disconnected, show black solid line if communication was reconnected.

Mission Commander Display

(2c) IRA – Convoy Attacked

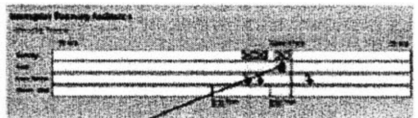


Clicking one of the red convoy icons (see above) on the IRA timeline will reveal further detail in the Map Display. A red X (see right) indicates on the spatial map where the convoy was hit. The red X will fade after 5 seconds.

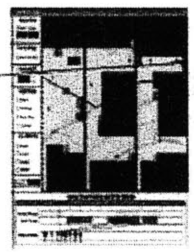


Mission Commander Display

(2d) IRA – UAV Destroyed

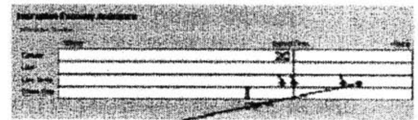


Clicking on the gray UAV icon (see above) will reveal further detail in the Situational Map Display. A transparent red X (see right) will be drawn on the spatial map to indicate which UAV was destroyed. The X will fade after 10 seconds.

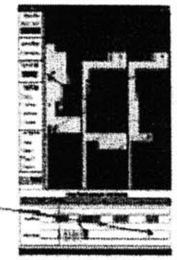


Mission Commander Display

(2e) IRA – Late Strike

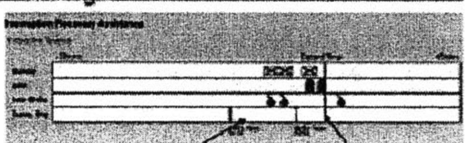


Clicking on the late strike icon (see above) will reveal further details in the Map Display. A black box (see right) will be drawn on the Strike Schedule panel to indicate which target will become a threat before the strike team will be able to eliminate it in the near future. Also, the other targets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



Mission Commander Display

(2f) IRA – Communication Status Change

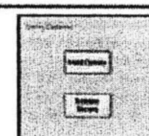


A solid black line indicates an event in which the communication link was restored. The timer below the line displays the total length of disconnect.

The dotted red line on the Comm. Stat panel indicates an event in which one of the communication links was broken (JSTARS, Strike Team, or Convoy). The timer below the line shows the duration of the disconnect.

Mission Commander Display

(3) Convoy Intervention Decisions



The Convoy Decisions panel enables you to:

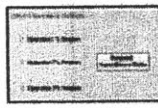
- **Hold the convoy** – i.e., send a command to the convoy to hold its current position.
- **Release the convoy** – i.e., send a command to the convoy to resume its progress on its planned path.

When the convoy is currently moving, the 'Hold Convoy' button is active, while the 'Release Convoy' button is grayed out, and vice versa when the convoy is currently hold.

Once either the Hold Convoy or Release Convoy button is selected (by touching it with the TabletPC pen), the corresponding command is sent to the convoy. An acknowledgement will be received from the convoy once they have received and are initiating your command.

Mission Commander Display

(4) JSTARS Intervention Decision



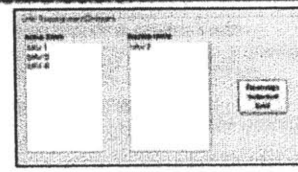
The JSTARS Surveillance Decision panel enables you to request additional
surveillance data from a nearby JSTARS (Joint Surveillance & Target Attack
Radar System), a multi-sensor aircraft, within range of your team's AOI.

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 within the selected sub-AOI. 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 (or will not have) time to surveil.

To request the JSTARS surveillance data, select the radio button corresponding to the desired operator region and then select the 'Request Surveillance Data from JSTARS'. A message will be

Mission Commander Display

(5) UAV Reassignment Intervention Decision



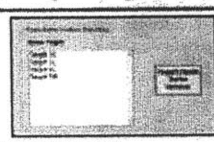
The UAV Reassignment Decision panel enables you to reassign one of your team's UAV to take over the remaining surveillance route of another UAV that has been destroyed.

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.**

Mission Commander Display

(6) Late Strike Reporting Detection



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. The **IRA Late Strikes panel** should assist you in identifying late strikes.

Threat Summary & Strike Schedule

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.

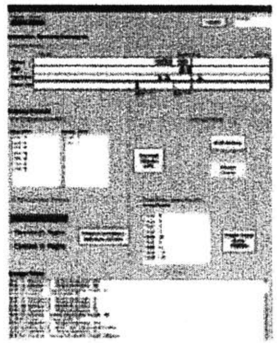
Mission Commander Display

(7) Message History

See previous section on message history.

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?



Advance slide when you are ready...

Begin Practice Sessions

Your Mission Priorities:

Equally high priority:

- Move the convoy through your AOI as quickly as possible
- Keep the convoy safe (i.e., free from target attacks)

Lower priority:

- Assist your operators in completing the assigned set of target designations
- Report late strikes
- Survey all roads in your AOI
- Complete Incidence Report documents after

Appendix I: Post-Tutorial Script

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

1) Mission objectives: Primary, Secondary objectives

2) Lose health for Convoy attacked, holding,

3) Interruptions may occur at any time, will be told how long the interruption will be, have 5 seconds to vacate the room, fill out incident report when returning.

4) Map Display (highlight the following):
-Filters
-UAVs fly to the corner at the end
-Threat envelopes, potential threat (explain how can get hit if youa re in the yellow but not red region), late strike
-Convoy doesn't get attacked until center inside the circle, use red envelopes

5) Mission Status Summary (highlight the following):
-UAV status (idle for >30 seconds, than click request)
-Operator performance
-Communication status (JSTAR)

6) Mission Commander Interface (highlight the following):
-Hold/Release Convoy (Convoy Communication Link)
-Reassign UAV only once (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

Appendix J: Interview Questions

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

1. Which interface did you look at the most?
2. Did you find the interruptions distracting enough to take your mind off the mission?
3. Did you use the IRA? If yes, how?
4. After interruption 2, did you notice that JSTARs was disabled or did you find out when you tried to use it?
5. Walk me through how you filled out the incidence report, specifically what tools or strategies did you use?
6. Do you have any other comments or suggestions about the usability of the interfaces or the mission?

Appendix K: Statistical Tests

Analysis of Variance (ANOVA) Test for Interruption Recovery Time

ANOVA Table for Interruption Recovery Time with Military Blocking Factor

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power(a)
BETWEEN SUBJECTS						
Assistance Type	82.980	1	82.980	1.173	0.307	0.166
Military Experience	339.176	1	339.176	4.796	0.056	0.508
Error	636.417	9	168.802			
WITHIN SUBJECTS						
Decision Difficulty	184.010	1	184.010	1.447	0.257	0.201
Decision Difficulty * Assistance Type	514.127	1	514.127	4.044	0.072	0.461
Error(Decision Difficulty)	1271.329	10	127.1329			

a Computed using alpha = .05

Non-Parametric Tests for Decision Accuracy Scores

Mann-Whitney U Test for Decision Accuracy Scores across Assistance Types

	Assistance Type
Mann-Whitney U	12.000
Wilcoxon W	33.000
Z	-1.173
Asymp. Sig. (2-tailed)	.241

Wilcoxon Signed Ranked Test for Decision Accuracy Scores across Decision Difficulty Levels

	Decision Difficulty
Z	-2.828
Asymp. Sig. (2-tailed)	.005

ANOVA Tests for Convoy Health Scores

ANOVA Table for Convoy Health with Military Blocking Factor

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Observed Power(a)
Corrected Model	18.250(b)	2	9.125	.648	.546	.127
Intercept	97020.083	1	97020.083	6893.532	.000	1.000
Assistance Type	8.167	1	8.167	.580	.466	.105
Military Experience	4.167	1	4.167	.296	.600	.078
Error	126.667	9	14.074			
Total	97165.000	12				
Corrected Total	144.917	11				

a Computed using alpha = .05, b R Squared = .126 (Adjusted R Squared = -.068)

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