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Interruption Management and Recovery in Time-critical Supervisory-level Tasks: A Literature Review

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The negative effects of interruptions on task performance in modern work environments are well documented. However, in most time-critical supervisory-level tasks such as emergency response and mission command and control, interruptions to supervisors may contain valuable information necessary for the execution of the task. In such cases, supervisors may need assistance to manage or recover from interruptions as efficiently and effectively as possible. This paper reviews the relevant interruption management and recovery literature to identify opportunities for research.

INTRODUCTION

Failure to recover from an interruption in a safety-critical task may have serious consequences. For example, a Northwest airplane crashed in 1998 as the flight crew forgot to finish the preflight checklist after they were interrupted by an air traffic control operator (NTSB, 1988). Failing to resume the preflight checklist after the interruption caused the crew to skip checking flaps which were in the wrong position and led the airplane to crash during take-off. The consequences of an incorrect decision could be even more drastic in settings like emergency response, command and control, and nuclear power plants. Supervisors in such settings are particularly prone to interruptions (Jett and George, 2003) due to high level of collaboration and multitasking present in these environments (Cooke et al., 2007; Cooke and Gorman, 2006). For example, in command and control settings, supervisors have to monitor both the mission status and the performance of other personnel to make tactical and time-critical decisions. In this paper, a review of the literature is presented which focuses on the problem of interruptions in time-critical work environments and on techniques for helping supervisors in such environments recover from interruptions as efficiently and as effectively as possible.

Literature on interruptions falls into three main categories: (1) effects of interruptions; (2) preventive measures to minimize or control the occurrence of interruptions, and (3) assisting recovery from interruptions. The literature primarily focuses on the first category and establishes that interruptions can have negative effects on individual and team task performance (e.g., Van Bergen, 1968; Kirmeyer, 1988; Cellier & Eyrolle, 1992; Czerwinski et al., 2000). In this paper, the research that has been conducted on the latter two categories, i.e., controlling the occurrence of interruptions and of assisting in recovery from interruptions is explored. McFarlane's seminal work (1998) is discussed first, which set the stage for modern interruption research by developing a taxonomy of interruptions in human computer interaction (HCI). The paper then provides a discussion of subsequent work on the development of techniques for preventing or finding an opportune time for interruptions. Finally, we present computational tools developed for assisting recovery from interruptions. The implications of previous research for time-critical supervisory-level tasks are discussed throughout.

MCFARLANE'S TAXONOMY (1998)

McFarlane (1998) proposed a taxonomy of human interruptions in HCI that consisted of four methods of interruption coordination:

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

McFarlane (2002) conducted a laboratory-based experiment to compare these four methods in a representative emergency response task. The results revealed that the four coordination methods have different effects on task performance. In general, the negotiated approach caused the best overall performance; however, the immediate approach showed a slight advantage over the negotiated approach with respect to the timeliness of interruption handling.

POST-MCFARLANE (1998) INTERRUPTION RESEARCH

Other researchers have taken the following two directions building on McFarlane's research:

- Interruption management, e.g., finding a more opportune time to interrupt, interruption methods, etc. (e.g., Altmann et al. 2004; Fogarty et al., 2005; Oulasvirta et al., 2006; Sen et al., 2006).

- Developing interruption recovery methods and technologies (e.g., Altmann et al., 2003; St. John et al., 2005; Scott et al., 2006; Wan et al., 2007).

Interruption Management

In line with McFarlane's taxonomy, researchers used different methods of coordination to investigate interruption management. McFarlane et al. (2005) applied the negotiation-based coordination method on the Aegis, a U.S. Navy weapon system, through the use of Human Alerting and Interruption Logistics (HAIL) mediation technology. HAIL is a decision-support system that delivers alerts based on the cognitive abilities of the human user. McFarlane's work showed that such systems could increase the human capacity for processing critical alerts and improve the situational awareness by changing the location of non-critical alerts to other display areas and by providing a negotiation-based on-demand access to information.

Bailey et al. (2006) expanded on McFarlane's negotiation-based solution and investigated the timing of interruptions. They found that interruptions occurring at the boundary between tasks and not during a task help mitigate their disruptive effects on completion times, error rates, and the level of annoyance and anxiety. Furthermore, Monk et al. (2004) focused on driver multitasking, in which attention is being switched back and forth between two tasks (e.g., a driver interacting with a navigational display). They too found that interruptions occurring in the middle of a task had the most negative effects, and suggested that non-critical alerts should be designed to interrupt drivers at the beginning or end of a subtask, such as before or after a lane change. However, identifying the boundaries between supervisory-level tasks, such as ones in military command and control settings, is challenging because the information in such work settings is dynamically changing and the task is normally ongoing and long.

Managing interruptions through the implementation of coordination methods was also studied in office work settings. Russell et al. (2007) evaluated email alerts as negotiable interruptions and conducted interviews with email users from different organizations and found that interruption handling strategies in office environments vary based on the situational parameters of both the primary task, in particular the goal, and the incoming email content (e.g., importance). In general, users claimed that they direct their actions and manage their attentional resources to achieve a task-related goal. These findings indicate that interruption management is dependent on task type and the cognitive complexity of the work. Thus, in order to develop efficient interruption management mechanisms, researchers should understand the task-specific cognitive and interruption processes. Sen et al. (2006) at IBM developed a collaborative Bayesian filtering algorithm, which is a learning-based algorithm (e.g., amazon.com book recommendations) to reduce interrupting alerts caused by collaborative tools, such as instant messaging or email, by filtering out unnecessary alerts. The algorithm was tested using a new technology called "FeedMe", which is an alert management system. Such automated interruption management support requires an automatic identification of the interruption source. Since majority of supervisory–level interruptions in modern work environments are in the form of "unexpected meetings and conversations" (Jett and George, 2003, p. 494), using such filtering mechanisms may be challenging within the context of supervisory-level tasks.

Dabbish et al. (2004) investigated the effects of interruptions on collaborative teamwork environments and found that awareness displays, which show an appropriate amount of information about the attentional state of the interrupted person, can mitigate task disruption and improve the efficiency of the interrupted task. They also found that being a part of a team motivates the interrupter to use the awareness display to interrupt at a more opportune time, which helps to improve the performance of the interrupted.

Although the majority of previous research frames interruptions to be negative, supervisory-level interruptions are sometimes sources of important information relevant to the task-at-hand and may have to be presented immediately. In such cases, facilitating interruption recovery becomes essential. Strategies to support efficient recovery from interruptions are discussed next.

Interruption Recovery

Majority of the previous interruption recovery research in time-critical settings is based on the work of Trafton et al. (2003) who conducted a task analysis of the interruption process and developed a model to describe this process (Figure 1). Trafton et al. (2003) expanded McFarlane's negotiation-based method and defined "interruption lag" as the time between when an interruption first becomes known (i.e., the interruption alert) and when the person begins to focus on the interruption (i.e., the secondary task). Altman et al. (2003) then proposed that interruption lag could be used as a preparatory stage for interruption and empirically proved that this preparation can reduce the time it takes to resume the primary task (i.e., "resumption lag"). The resumption lag is also known as reorientation time (Gillie and Broadbent, 1989) and interruption recovery time (Scott et al., 2006). This concept is very important in that it focuses the problem of interruption recovery to the problem of reducing the resumption lag.

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

Oulasvirta et al. (2006) expanded on Altman and Trafton's theoretical model and proposed that in order to mitigate the effects of interruptions on memory, task representations should be "safeguarded", that is, stored in a way to be later accessed rapidly and reliably. Oulasvirta et al. (2006) also expanded on Altman et al.'s notion of encoding the goal. They argued that experts develop hierarchical knowledge representations called "retrieval structures" and use them to encode and retrieve the task after an interruption.

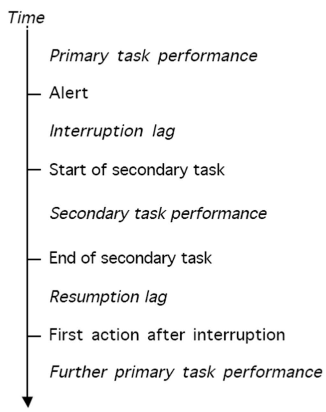

Figure 1. Interruption recovery process (modified from Trafton et al., 2003)

Change blindness: An important phenomenon that should be considered in understanding interruption recovery, especially in dynamic environments, is change blindness. Change blindness happens when humans fail to detect changes within a visual scene, often after a visual disruption (Cavanaugh & Wurtz, 2004). Most supervisory-level tasks are complex monitoring tasks and hence are especially prone to change blindness. For example, detecting changes in mission command and control is essential for gaining situational awareness. Previous research showed that interruptions, even in short duration (e.g., screen flickers), may cause the observer to fail to detect substantial changes in a scene or display (Rensink, 2000). It is also well documented that looking away from the computer screen may cause change blindness (e.g., Rensink et al., 1997).

Verbal and visual cues: One mitigation technique for change blindness is to use visual and auditory cues to assist in task resumption. Altman and Tranfton (2004) and Trafton et al. (2005) found that subtle environmental cues such as a cursor or an eyeball image as place keepers reduce interruption recovery times and facilitate task resumption. The use of verbal cues was also studied as an alternative interruption recovery technique. Daniels et al. (2002) implemented an interruption recovery tool using a spoken dialogue interface to mitigate interruptions to a primary task of tracking military logistics. Using verbal queries, users could ask simple questions regarding this interrupted task, such as their status before the interruption. While verbal queries might be effective in static environments, in dynamic time-critical environments like command and control, there are often situations that need immediate attention after the resumption of the interrupted task (e.g., a tactical decision) which makes the utility of verbal queries limited.

Instant replays: Another approach to mitigate change blindness is to provide an "instant replay" feature that enables users to review the interrupted period usually with higher speed (St. John et al., 2005; Scott et al., 2006).

St. John et al. (2005) compared the effectiveness of event replays in a realistic simulation of a naval air warfare task. Using the event replay, participants were able to replay the video of the interrupted period (at high speed) for important events. They compared the event replay feature with an event history log tool called Change History EXplicit (CHEX), which has previously shown promise in mitigating change blindness (Smallman and St. John, 2003). The intent of CHEX was to provide constant awareness of the important changes in a flight change detection task by dynamically populating a table with bookmarks of events in rows, which could be sorted by the user for different tasking (see Figure 2).

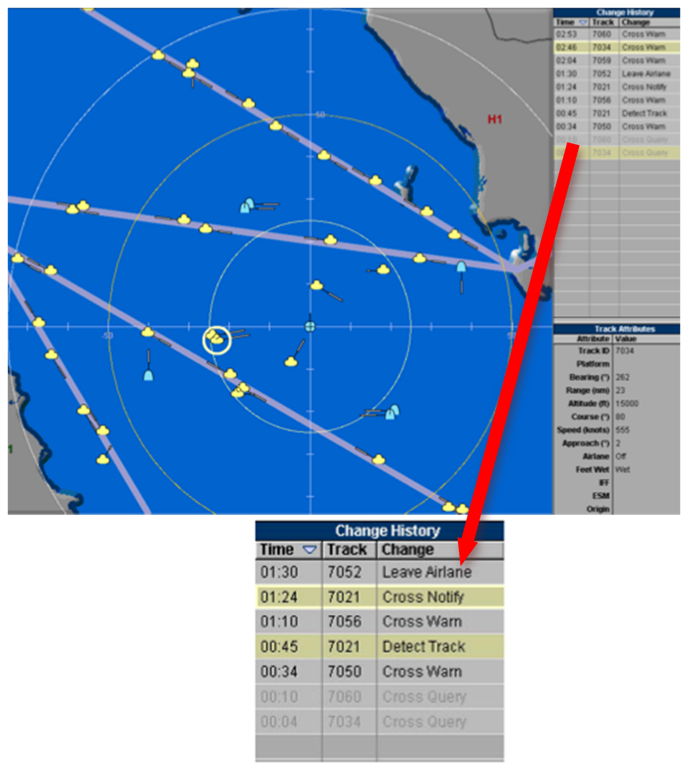

Figure 2. CHEX history table embedded in a situational awareness display (modified from St. John et al., 2005, Figures 1&2)

Despite their intuitive appeal, St. John et al. (2005) found instant replays to offer no change detection support. In fact, users with no assistance (base condition) performed better. St. John et al. (2005) attribute this result to the delay added to task resumption by reviewing instant replays. On the other hand, participants using the event history log identified changes faster and more reliably than participants who were not provided with assistance as well as participants who were provided with the instant replay tool.

Scott et al. (2006) posited that the inherent design limitations of the event replay tool in St. John et al.'s study might have influenced the results, as the tool did not highlight particular events of importance nor enable the user to select events to review. According to Scott et al. (2006), CHEX performed well since it provided concise summary of important events while enabling the users to interact with the tool to select important events to review. The authors also proposed an alternative design, combining defining features of event history logs and instant replay tools, and evaluated this design within the context of supervisory control of unmanned aerial vehicles (UAVs). In particular, they investigated an interruption recovery tool provided on a peripheral display in the primary task environment, called the Interruption Assistance Interface (IAI). As shown in Figure 3, IAI consisted of a replay window, an event timeline, and animation controls. The information on the IAI was dynamically updated when events happened.

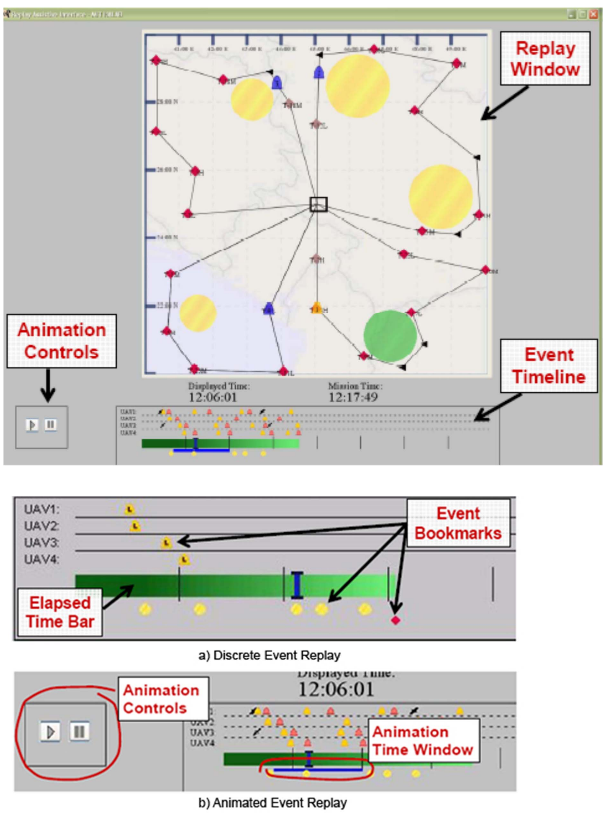

Figure 3. Interruption Assistant Interface (top) Discrete (bottom, a) vs. Animated Event Replays (bottom, b) (from Scott et al., 2006)

They evaluated two versions of the IAI. The first one was a "discrete" replay version that allowed users to select an icon representing a historical event on an interactive timeline. Once the icon was selected, the replay window showed the state of the main task display (a tactical map) at the time the event has occurred. The second version was an "animated" replay, in which users could view an accelerated animated sequence of historical events within a desired time period. Empirical evidence showed that IAI's replay tool, especially the "discrete" replay, was beneficial for interruption recovery, particularly when complex system changes had occurred during the interruption.

Wan et al. (2007) extended this concept in their interruption recovery assistant (IRA), which provided a similar interactive timeline of historical events (e.g., UAV destroyed icon). When IRA was used to support mission commanders recover from interruptions during simulated UAV team mission operations, IRA was found to significantly reduce the interruption recovery time, and improve decision accuracy (Sasangohar, 2009).

DISCUSSION AND CONCLUSION

Time-critical tasks, such as command and control and emergency response, are particularly susceptible to the negative effects of interruptions. As the situational information dynamically changes in such tasks, distractions can result in important information being missed and incorrect decisions being made (Hughes et al., 1992). Since safety-critical decisions are often being made in these task environments, the outcome of an incorrect decision may be dire.

Although literature provides operator-level interruption support research (e.g., St. John et al., 2005; Scott et al., 2006), minimal research attention has been given to assist team supervisors in recovering from interruptions. Due to the collaborative and multitasking nature of time-critical command and control tasks (Cooke et al., 2006; Cooke et al., 2007), supervisors are more prone to frequent interruptions (Jett & George, 2003).

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

In this paper, two general investigative directions in mitigating the negative effects of interruptions were reviewed: 1) pre-interruption (interruption management) support: research that investigates the effects of interruptions and that studies preventive measures to control the occurrence of interruptions (e.g., Dabbish et al., 2004; McFarlane, 2005; Bailey et al., 2006; Sen et al., 2006), and 2) post-interruption (interruption recovery) support: research that focuses on providing assistance to recover from interruptions (e.g., St. John et al. 2005; Trafton et al., 2005; Scott et al., 2006; Wan et al., 2007).

In general, existing pre-interruption management strategies to prevent interruptions or to find more opportune times to interrupt are suitable for static tasks such as editing a document but are not well suited for highly dynamic work settings like command and control because interruptions in these settings can provide valuable information that is directly related to the decisions at hand and hence may need to be allowed immediately. On the other hand, interruption recovery strategies reviewed in this paper, in particular providing concise history of important events, have shown promise in mitigating the negative effects of interruptions in time critical supervisory-level environments.

Several important research questions need to be considered for future work. For example, *what are the effects of interruptions on cognition? What are the domain-specific sources of interruptions?* Since interruptions in time-critical settings may convey important information, at times relevant to the task-at-hand, it is important to investigate *what factors contribute to an interruption being negative or positive*, and *how to mitigate the effects of negative interruptions while managing the positive ones.* In addition, further research is needed to investigate *visualization techniques to assist interruption recovery in dynamic task environments*.

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