Industry Issue Paper

An Eye for the Air Traffic Controller Workload

by Ulf Ahlstrom

The purpose of this paper is to outline an approach for workload measurements and optimization of air traffic systems and displays that match controller needs. Ill-designed systems and displays can cause safety hazards for aircraft by increasing controller workload and reducing situation awareness. To prevent this situation, researchers need to develop systems that allow effortless monitoring while being attentive to operator needs. Such systems, once developed, will increase operator and system efficiency and increase the safety of airline operations.

INTRODUCTION

Everybody knows that "doing too many things at once" can be frustrating, mentally intense, and very stressful. Not surprisingly, people have a natural tendency to avoid tasks or situations that can push their capabilities beyond the limit. The problem, however, is that not all work situations permit an easy escape or regulation of mental effort. With the increasing complexity of future transportation systems (ATCA 2006; Wreathall et al. 2007), regulation of operator workload becomes an even more critical issue. Ideally, we would be able to identify factors that increase cognitive load and use this knowledge to optimize operators' work environment.

Although the problems with designing new systems are multifaceted and highly context dependent, the increasing complexity of control systems and an increasing reliance on advanced information displays are two major factors contributing to cognitive load (Ahlstrom 2005). While automation can reduce the complexity of an operator's task and increase safety of operations, it can also create other system contingencies that can negatively affect operator performance. Automated systems are less error-prone than human operators, but they are also less capable of finding generic solutions for system failures that were unforeseeable and therefore not implemented in system algorithms. For future air traffic control environments envisioned in the Next Generation Air Transportation System (NextGen) architecture (ATCA 2006), some of the proposed automation processes will likely create unknown system-operator contingencies that affect operators' cognitive load. For example, NextGen will move from a traditional distribution of graphical and text-based information to automatic decision processes, circumventing the need for operator inference and decision-making. From a system perspective, this may optimize the use of available air space during normal traffic operations. However, it could also reduce operators' awareness levels during monitoring and increase workload if automation performs less than perfectly.

There are also risks involved with reduced operator awareness during decision-making in the case of unusual events, system anomalies, or emergencies. Also, we do not know the effects on operators' decision-making under future conditions characterized by a much greater level of uncertainty. One example is NextGen's move to probabilistic decision-making where automation implements solutions based on event probabilities. This could potentially have consequences for operators who perform monitoring tasks. For example, the specification of weather attributes by means of single-event probabilities is optimal for automation but not always correctly interpreted by humans (Gigerenzer et al. 2005).

THE WORKLOAD CONCEPT

In the air traffic domain, researchers use the concept of mental workload and study what factors influence it. Interestingly, while most operators have an intuitive understanding of what workload is, and why too much of it can be bad, researchers still argue about how to measure it and how to avoid increasing it in new systems. Although there is no single definition of workload that everyone agrees upon, there are plenty of theories and research (Stein 1998). On a semantic level, we can define mental workload as the total cognitive effort an operator must exert to perform a task. By this definition, when workload is low, very little cognitive effort is required and the operator can easily complete the task. On the other extreme, when workload is very high, so much cognitive effort is required that an operator is likely to leave the task unfinished. These two workload extremes, the low and the very high, are the easiest ones to assess in work situations. The difficult part is to assess fluctuations in workload levels between these two extremes that can negatively impact operator performance.

SELF-REPORTED WORKLOAD RATINGS

One of the most commonly used measures of workload collects an operator's direct estimate of the cognitive workload experienced at a given moment in time. The advantage of these self-reported workload ratings is the ease of application. In many situations, recordings of physiological measures are too obtrusive or too impractical for use, leaving subjective ratings as the only viable alternative. However, subjective workload ratings are usually collected during fixed time intervals while operators perform a task or at the end of task completion. Because the measure is periodic rather than continuous, there is a potential for overlooking more rapid and transient fluctuations in workload. In some cases, subjective ratings can also be impractical and interfere with the primary task. An example of when subjective ratings are difficult to use is when operators are using system tools (e.g., during interactions with tools that detect conflicts between aircraft or when using dynamic weather displays).

EYE MOVEMENT ACTIVITY ANALYSIS

As an alternative to using subjective workload ratings, researchers have also used various physiological measures like core body temperature, heart rate, blood pressure, and galvanic skin response to measure mental workload (Stein 1998). Still other researchers have used eye-tracking applications to record eye movement activities that correlate with cognitive demands. For example, research has found that blink duration and fast eye movement jumps (i.e., saccade distance) generally decline as a function of increased mental workload, while the pupil diameter increases as a function of cognitive demands (Ahlstrom and Friedman-Berg 2006).

Eye movement monitoring is especially relevant for air traffic control because air traffic control systems rely heavily on the human visual channel during operations. Also, eye movement activity measures can provide a more continuous measure and detect differences in mental workload that are not reflected in subjective workload ratings. Eye movement data can be used to identify specific system display components (e.g., data fields, text, and graphic elements) that produce changes in workload that otherwise would have been impossible to detect. By collecting eye movement data, not only can researchers tell when a change in workload occurs, it is also possible to identify what the controller was looking at when it happened.

IMPLICATIONS FOR AIR TRAFFIC CONTROL AND AIRLINE SAFETY

As more complex and dynamic systems are introduced in the transportation domains, it is important to identify human operator capabilities and limitations in their response to system demands.

Because the nature of operator tasks and workload are likely to change, workload assessments play an important role in the development of future control systems. Eye movement activity measures could play an important role in this development. First, they allow for a detailed and continuous measure of operator workload. Second, they provide a means to optimize systems and displays by enhancing information layout and thereby reducing search times. Third, developers can use eye movement data for attention aware systems that monitor operator status and provide support to controllers when needed.

DESIGN OF AIR TRAFFIC CONTROL SYSTEMS

Eye movement recordings can help designers avoid systems that could have a negative impact on operator workload and vigilance. An increase in operator workload can negatively affect performance and lead to potentially higher risks for operating hazards. For example, eye movement recordings are useful for scan path (i.e., sequences of fast eye movements and eye fixations) analysis of controller interactions with displays (Goldberg and Kotval 1999) and systems. Eye movement analysis can help designers optimize displays and visual tools for efficient scan path behavior by optimizing the grouping of information and by reducing operator search times.

MONITORING OF WORKLOAD BY ATTENTION AWARE SYSTEMS

The recording of eye movement data is useful for providing workload estimates during the development of air traffic control systems and displays. The monitoring of an operator's eye movement activity can potentially reveal operator confusion, fatigue, or level of expertise, and help researchers develop display techniques that optimize the presentation of visual information during monitoring tasks (Toet 2006).

Operator workload and awareness of a system's operating state are also issues in other transportation domains. For instance, there are concerns about system performance associated with operator workload and system awareness in technologies like positive train control (Wreathall et al. 2007) where the systems used are capable of preventing train collisions, speed-related derailments, and casualties or injuries to roadway workers. These systems vary widely in complexity and sophistication based on the level of automation and the degree of operator control. Similarly, researchers have investigated operator workload, stress, and fatigue of railroad dispatchers (Popkin et al. 2001). Eye movement recordings have also been used to investigate driver inattention and gaze concentration (Victor 2005).

Using a workload measure concept, researchers have already developed systems for drivers using modern in-vehicle information and communication devices. By using an adaptive man-machine interface that filters information presentation to drivers, Piechulla et al. (2003) created a real-time workload estimator that alerts the driver based on the current workload and traffic situation. Other researchers have also developed similar designs using voice information to detect driver workload (Uchiyama et al. 2004; Wood et al. 2004).

Often referred to as attention aware systems, these systems are attentive to an operator's cognitive state and needs, and use the operator's gaze behavior to track and adapt the system over time (Roda and Thomas 2006). Attentive interfaces can therefore use eye movement activity to infer the user's cognitive state, anticipate operator needs, and prioritize the information presented to operators, thereby reducing attentional and cognitive workload.

FUTURE WORK

While some transportation domains have developed in-vehicle devices that use eye movement data, no air traffic system uses eye movement data and there are currently no attention aware systems for operational use. With the projected increase in air traffic operations and the increased complexity

of future systems, attention aware systems need to be developed that provide support to controllers during operations. The main hypotheses for future work are that attention aware systems actually provide controllers with support that:

1. reduces controller workload during normal operations and operations during system anomalies,
2. increases operational efficiency by means of an increased traffic throughput,
3. enhances aircraft safety of flight.

By testing these hypotheses during research and system development, researchers should be able to quantify the effect on controller workload, operational efficiency, and traffic safety from the use of attention aware systems. Once developed, these systems will provide the support needed to manage future increases in air traffic while at the same time increase the safety of aircraft operations.

DISCUSSION

With proposed changes to the National Airspace System automation (ATCA 2006), factors like an increased traffic load and new procedures have the potential to increase display complexity and operator workload. In other situations, the relevant system information might not be directly available in a display, but hidden in automation processes. During automation failures, anomalies, or other system irregularities, operators are likely to face difficulties in being "aware" of what is actually happening in the system (Kaber et al. 2006). Operators that monitor automation and have to be prepared for system intervention are especially at risk (Ahlstrom and Longo 2003; Metzger and Parasuraman 2005).

One example of a future system technology that could have unintended consequences on controller workload is the use of the Global Positioning System (GPS). On the one hand, this satellite-based technology will provide much more accurate position data compared to current ground-based radar surveillance. This will increase operational efficiency and safety of airline operations. It also means that future aircraft separation distances can be reduced from five miles to three miles for all air traffic operations. An increased volume of future traffic necessitates this decrease in separation standards during NextGen operations. However, the monitoring controller now has more densely spaced aircraft in the sector with an increased risk for hazardous aircraft maneuvers in the event of a system failure. Therefore, there is an even greater need for future attention aware systems that monitor controller workload and situation awareness and provide support in time-critical situations. For example, if the monitoring system detects high workload levels, it could capture and guide the operator's attention to relevant display information. Also, workload levels could be used to determine when to assist a controller or when to divide a stream of aircraft across multiple air traffic sectors.

The development of future automation systems is likely to be complex. On one hand, these systems need to function with high reliability and accuracy to enhance the flow of traffic and increase the safety of airline operations. On the other hand, they need to contain support mechanisms for operator intervention and regulation of workload. The development of attention aware systems could provide an important part of the air traffic system design. By supporting operators through monitoring, diagnosis, and knowledge management, system support can be provided for control and safety of operations. This is important for the control of any complex transportation system, but vital for mission-critical systems like air traffic control. Eye movement analysis can provide an input to attention aware systems. There is an old saying that "the truth is in the eyes of the beholder." As we develop future air traffic control systems, this statement might be revised to "the truth is in the eye of the controller."

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