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Automation and Situation Awareness

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Automation represents one of the major trends of the 20th century. The drive to provide increased levels of control to electro-mechanical systems, and with it a corresponding distancing of the human from direct system control, has grown out of the belief that automated systems provide superior reliability, improved performance and reduced costs for the performance of many functions. Through the auspices of the technological imperative, automation has steadily advanced as means have been found for automating physical, perceptual, and, more recently, cognitive tasks in all kinds of systems.

In many cases automation has provided the desired benefits and has extended system functionality well beyond existing human capabilities. Along with these benefits, however, a certain price has been extracted. The role of the human operator has changed dramatically. Instead of performing tasks, the human's job has become that of monitor over an automated system — a role people are not ideally suited to.

Contrary to the implication of the term "automated", humans have remained a critical part of most automated systems. They must monitor for failures of the automated system and the presence of conditions the system is not designed to handle. Furthermore, as most automation has been piece-meal, covering certain functions but not others, humans have remained in the system as integrators — monitoring the automation for some functions and performing others themselves.

Since the systems to be monitored continue to increase in complexity with the addition of automation, an increased trend towards large catastrophic failures often accompanies the incorporation of automation (Wickens, 1992; Wiener, 1985). When things go wrong, they go wrong in a big way. In examining these failures, it becomes apparent that the coupling of human and machine in the form of observer and performer is far from perfect in terms of optimizing the overall functioning of the joint human-machine system.

A central short-coming associated with the advent of automated systems has been dubbed the out-of-the-loop performance problem. When acting as monitor of an automated system, people are frequently slow in detecting that a problem has occurred necessitating their intervention. Once detected, additional time is also needed to determine the state of the system and sufficiently understand what is happening in order to be able to act in an appropriate manner. The extra time associated with performing these steps can be critical, prohibiting performance of the very activities the human is present to deal with. The result ranges from a slight delay in human performance to catastrophic failures with major consequences.

In 1987, a Northwest Airlines MD-80 crashed on take-off at Detroit Airport due to an improper configuration of the flaps and slats, killing all but 1 passenger (National Transportation Safety Board, 1988). A major factor in the crash was the failure of an automated take-off configuration warning system, upon which the crew had become reliant. They did not realize the aircraft was improperly configured for take-off and had neglected to check manually (due to other contributing factors). When the automation failed, they were not aware of the state of the automated system or the critical flight parameters they counted on the automation to monitor.

In 1989, a US Air B-737 failed to take-off at New York's LaGuardia Airport, landing in the nearby river (National Transportation Safety Board, 1990). The precipitating cause was an accidental disarming of the autothrottle. Neither the captain nor the first officer monitored the critical flight parameters in order to detect and correct the problem, thus the take-off was not aborted in a timely manner, resulting in the loss of the aircraft and two passengers.

In 1983, a Korean Airlines flight was shot down over the (then) USSR with no survivors. The aircraft was interpreted as hostile when it traveled into Soviet airspace without authorization or radio contact. Although critical equipment was never recovered, it is believed that an erroneous entry was made into the flight navigation system early in the flight (Stein, 1983). The crew unknowingly flew to the wrong coordinates, reliant on the automated system and unaware of the error.

In each of these cases, the human operators overseeing the automated systems were unaware of critical features of the systems they were operating. They were unaware of the state of the automated system and were unaware of the aircraft parameters the automation was responsible for.

In addition to difficulties in detecting these types of automation errors, it is also frequently difficult for human operators to correctly understand what the problem is, once they have detected that something is amiss. In the US Air accident, for instance, both crew members tried to gain control of the aircraft, but were unable to due to the mis-trimmed rudder. The lost time associated with trying to overcome the aircraft control problem without understanding what was causing it fatally delayed aborting the take-off until it was too late.

With many automated systems, partially due to their complexity, understanding the meaning of displayed information, once attended to, can represent a significant difficulty. For instance, in aircraft systems, pilots have reported significant difficulties in understanding what their automated flight management systems are doing and why (Sarter & Woods, 1992; Wiener, 1989). Similarly, the accident at the Three Mile Island nuclear power plant was attributed to an erroneous over-ride of the automated emergency handling system by the human operators. They had misdiagnosed the situation based on displayed information and believed an excessive coolant level was causing the problem rather than too little coolant (Wickens, 1992). They did not correctly understand the meaning of the information that was displayed to them.

Each of these problems can be directly linked to a lower level of *situation awareness* that exists when people operate as monitors of automated systems. Situation awareness (SA), a person's mental model of the world around them, is central to effective decision making and control in dynamic systems. This construct can be severely impacted by the implementation of automation.

SITUATION AWARENESS

Originally a term used in the aircraft pilot community, situation awareness has developed as a major concern in many other domains where people operate complex, dynamic systems, including the nuclear power industry, automobiles, air traffic control, medical systems, teleoperations, maintenance, and advanced manufacturing systems. Achieving situation awareness is one of the most challenging aspects of these operators' jobs and is central to good decision making and performance. Hartel, Smith and Prince (1991) found poor situation awareness to be the leading causal factor in military aviation mishaps. In a recent review of commercial aviation accidents, 88 percent of those with human error involved a problem with situation awareness (Endsley, 1994a). Situation awareness clearly is critical to performance in these environments.

Situation awareness is formally defined as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future"* (Endsley, 1988a). Situation awareness involves perceiving critical factors in the environment (Level 1 SA), understanding what those factors mean, particularly when integrated together in relation to the person's goals (Level 2 SA), and at the highest level, an understanding of what will happen with the system in the near future (Level 3 SA). These higher levels of situation awareness are critical for allowing decision makers to function in a timely and effective manner.

For instance, in an aircraft environment, operators must be aware of critical flight parameters, the state of their on-board systems, their own location and the location of important reference points and terrain, and the location of other aircraft along with relevant flight parameters and characteristics. This information forms the "elements" they need to perceive to have good Level 1 SA. But a great deal has to do with how the operators interpret the information they take in. They need to comprehend that a certain pattern of flight parameters indicates that they are near stall point, or that the displayed altitude is below their assigned altitude. This understanding forms their Level 2 SA. At the highest level, Level 3 SA, their understanding of the state of the system and its dynamics can allow them to be able to predict its state in the near future. A group of enemy aircraft flying in a particular formation will thus be projected to attack in a given manner. With accurate and complete situation awareness, operators can act to bring their systems into conformance with their goals.

IMPACT OF AUTOMATION ON SITUATION AWARENESS

Automation can be seen to directly impact situation awareness through three major mechanisms (1) changes in vigilance and complacency associated with monitoring, (2) assumption of a passive role instead of an active role in controlling the system, and (3) changes in the quality or form of feedback provided to the human operator (Endsley & Kiris, in press). Each of these factors can contribute to the out-of-the-loop performance problem. In addition, automated systems, by nature of their complexity, also challenge the higher levels of situation awareness (comprehension and projection) during ongoing system operations.

Vigilance, Complacency and Monitoring

There is a long history of cases in which operators are reportedly unaware of automation failures and do not detect critical system state changes when acting as monitors of automated systems (Ephrath & Young, 1981; Kessel & Wickens, 1982; Wickens & Kessel, 1979; Young, 1969). Although monitoring failures have typically been associated with simple, low-event tasks, Parasuraman (1987) concludes that "vigilance effects can be found in complex monitoring and that humans may be poor passive monitors of an automated system, irrespective of the complexity of events being monitored". There are many cases of problems in monitoring aircraft automation. Billings (1991) reports that the probability of human failure in monitoring automation increases when devices behave reasonably but incorrectly, and when operators are simply not alert to the state of automation.

Complacency, over-reliance on automation, is one major factor associated with a lack of vigilance in monitoring automation. Complacency has been attributed to the tendency of human operators to place too much trust in automated systems (Danaher, 1980; Parasuraman, Molloy, & Singh, 1993; Wiener, 1985). Singh, Molloy and Parasuraman (1993) found that complacency was a function of a person's trust in, reliance on and confidence in automation. Trust in the automated system is a critical factor necessary for it to be employed by operators (Lee & Moray, 1992; Riley, 1994). Associated with this trust, however, operators may elect to neglect the automated system and the system parameters overseen by the automation in favor of other tasks through a shifting of attention (Parasuraman, Mouloua, & Molloy, 1994), resulting in low situation awareness on these factors. The demands of other tasks in complex, multi-task environments have also been directly linked to complacency effects (Parasuraman, et al., 1993). As an operator's attention is limited, this is an effective coping strategy for dealing with excess demands. The result, however, can be a lack of situation awareness on the state of the automated system and the system parameters it governs.

Monitoring problems have also been found with systems that have a high incidence of false alarms, leading to a lack of trust in the automation. Wiener and Curry (1980) and Billings (1991) report on numerous failures by aircrews to heed automatic alarms, leading to serious accidents. Even though the system provides a noticeable visual or auditory signal, the alarms are ignored or disabled by flight crew who have no faith in the system due to its high false alarm rate.

Thus significant reductions in situation awareness can be found with automated systems, as people may (1) neglect to monitor the automation and its parameters, (2) attempt to monitor them, but fail due to vigilance problems, or (3) be aware of problems via system alerts, but not comprehend their significance due to high false alarm rates.

Active vs. Passive

In addition to vigilance problems, the fact that operators are passive observers of automation instead of active processors of information may add to their problems in detecting the need for manual intervention and in re-orienting themselves to the state of the system in order to do so. Evidence suggests that the very act of becoming passive in the processing of information may be inferior to active processing (Cowan, 1988; Slamecka & Graf, 1978). This factor could make a dynamic update of system information and integration of that information in active working memory more difficult.

In a recent study, Endsley and Kiris (in press) found that subjects' situation awareness was lower under fully automated and semi-automated conditions than under manual performance in an automobile navigation task. Only level 2 SA, understanding and comprehension, was negatively impacted, however; Level 1 SA was unaffected. Thus, although they were aware of low level data (effectively monitoring the system), they has less comprehension of what the data meant in relation to operational goals. The out-of-the-loop performance problem associated with automation was observed in the automated conditions.

This finding was specifically attributed to the fact that operators in the automated conditions were more passive in their decision making processes, drawing on the automated expert system's recommendations. Under the conditions of the experiment, there was no change in information displayed to the operators and vigilance and monitoring effects were insufficient to the explain the situation awareness decrement. Turning a human operator from a performer into an observer can, in and of itself, negatively effect situation awareness, even if the operator is able to function as an effective monitor, and this can lead to significant problems in taking over during automation failure.

Feedback

A change in the type of system feedback or a complete loss of feedback has also been cited as a problem associated with automation (Norman, 1989). "Without appropriate feedback people are indeed out-of-the-loop. They may not know if their requests have been received, if the actions are being performed properly, or if problems are occurring" (Norman, 1989, p. 6). He attributes this problem largely to an erroneous belief by system designers that information on certain parameters is no longer needed by system operators once relevant functions are assumed by automation.

In some cases, critical cues may be eliminated with automation and replaced by other cues that do not provide for the same level of performance. In many systems, important cues may be received through auditory, tactile or the olfactory senses. When processes are automated, new forms of feedback are created, frequently incorporating more accurate visual displays; yet the fact that information is in a different format may make it harder to assimilate with other information or less salient in a complex environment. Young (1969) and Kessel and Wickens (1982) found that proprioceptive feedback received during manual control was important to performance and denied in automated tracking tasks in which information was only presented visually. The development of electronic fly-by-wire flight controls in the F-16 led to problems in determining airspeed and maintaining proper flight control, as the vibration information that usually came through the flight stick was suddenly missing (even though the needed information was clearly indicated on traditional visual displays) (Kuipers, Kappers, van Holten, van Bergen, & Oosterveld, 1989). Artificial stick-shakers are now routinely added to fly-by-wire systems to put back in the feedback that operators are accustomed to (Kantowitz & Sorkin, 1983).

In some cases, the design of the automated system intentionally conceals information from the operator. Some autofeathering systems, for instance, have neglected to notify pilots of their actions in shutting down engines, leading to accidents (Billings, 1991). In some notable accidents, the fact that the automated system had failed was not clearly indicated to the operator, as in the Northwest Airlines accident in Detroit (National Transportation Safety Board, 1988). In addition, there is a tendency for some displays to eliminate raw system data, in favor of processed, integrated information. Important information as to the source of information, its reliability, or the value of constituent data underlying the integrated information may be unavailable. Billings (1991) notes that the clarity of the integrated displays may be seductive, yet highly misleading if such underlying information is not known.

A noted problem in many systems is the lack of information salience that may accompany automation. Frequently displays associated with complex automated systems involve computerized CRT screens with information imbedded in hierarchical displays that may be associated with various system modes. Problems with getting lost in menus, finding the desired display screen, and interpreting cluttered displays have been noted. The increased display complexity and computerized display format reduces the perceptual salience of information, even if it is available. In a complex environment with many activities going on, it is easy for operators to loose track of such information.

Either intentionally or inadvertently, the design of many systems posses a considerable challenge to situation awareness through the elimination of or change in the type of feedback provided to operators regarding the system's status. Unless very careful attention is paid to the format and content of information displays, these issues can easily sabotage situation awareness when operators are working with automated systems.

Lack of Understanding of Automation

One of the major impediments to the successful implementation of automation is the difficulty many operators have in understanding automated systems, even when they are attending to them and the automation is working as designed. This may be partially attributed to the inherent complexity associated with many of these systems, to poor interface design and to inadequate training.

The development and maintenance of situation awareness involves keeping up with a large quantity of rapidly changing system parameters, and then integrating them with others parameters, active goals and one's mental model of the system to understand what is happening and project what the system is going to do. This allows operators to behave proactively to optimize system performance and take actions to forestall possible future problems. As complexity increases (as it is apt to do with automation), this task becomes even more challenging. The number of parameters increases, and they change and interact according to complex underlying functions. Achieving an accurate mental model of the system can be very difficult, and this taxes the ability of the operator to attain the higher levels of situation awareness (comprehension and projection) from information that is perceived. By adding to system complexity, therefore, automated systems may make achieving good situation awareness more difficult.

Wiener (1989) has documented many problems with a lack of understanding of automated systems in aircraft by the pilots who fly with them. McClumpha and James (1994) conducted an extensive study of nearly 1000 pilots from across varying nationalities and aircraft types. They found that the primary factor explaining variance in pilots' attitudes towards advanced technology aircraft was their self-reported understanding of the system. While understanding tended to increase with number of hours in the aircraft, this also was related to a tendency to report that the quality and quantity of information provided was less appropriate and more excessive. Although pilots are eventually developing a better understanding of automated aircraft with experience, the systems do not appear to be well designed to meet their information needs. Rudisill (1994) reported from the same study that “what’s it doing now”, “I wonder why its doing that”, and “well I’ve never seen that before” are widely heard comments in advanced cockpits, echoing similar concerns by Wiener (1989).

Many of these problems clearly can be attributed to standard human factors short-comings in interface design. For instance, transitions from one system mode to another may not be salient, designated by small changes in the displayed interface, yet creating very different system behavior. Although the systems are operating properly, operators may be confused as they misinterpret observed system behavior in light of their mental model of a different system mode.

With increased complexity, proving information clearly to operators so that they understand the system state and state transitions becomes much more challenging. Operators may rarely see certain modes or combinations of circumstances that lead to certain kinds of system behavior. Thus, their mental models of the systems may be incomplete. This leaves operators unable to properly interpret observed system actions and predict future system behavior, constituting a significant situation awareness problem.

Although problems with complexity and interface design are somewhat peripheral to automation per se (i.e. these problems also exist in many systems quite apart from any automation considerations), these issues often plague automated systems, and can significantly undermine operator situation awareness in working with automated systems.

Benefits to Situation Awareness

It should be noted that automation does not always result in these types of problems. Wiener (1985) points out that automation has, for the most part, worked quite well, and has accompanied a dramatic reduction in many types of human errors. Furthermore, he believes that it may improve situation awareness by reducing the display clutter and complexity associated with manual task performance, and through improved integrated displays (Wiener, 1992; 1993).

It has been suggested that automation may also improve situation awareness by reducing excessive workload (Billings, 1991). Curry and Ephrath (1977) found that monitors of an automatic system actually performed better than manual controllers in a flight task. As monitors, the authors argued, subjects may have been able to distribute their excess attention to other displays and tasks.

Recent research, however, demonstrates a certain degree of independence between situation awareness and workload (Endsley, 1993a). Workload may only negatively impact situation awareness at very high levels of workload. Low situation awareness can also accompany low levels of workload. If workload is reduced through automation, therefore, this may not translate into higher situation awareness.

Furthermore, whether automation actually results in lower workload remains questionable. Wiener’s (1985) studies showed that pilots report automation does not reduce their workload, but actually may increase it during critical portions of the flight. Many recent studies are beginning to confirm this. Harris, Goernert, Hancock, and Arthur (1994) and Parasuraman, Mouloua, and Molloy (1994) showed that operator initiation of automation under high workload may increase workload even more. Riley (1994) augments this with his finding that a subject’s choice to use automation for a task is not related to the workload level of the task. Grubb et. al. (1994) showed that workload actually was fairly high in tasks where humans must act as monitors over a period of time, as they do with automated systems. Automation in many ways may serve to increase workload, particularly when workload is already high. Bainbridge (1983) called it the irony of automation that when workload is highest automation is of the least assistance. Despite this, however, workload remains the fundamental human factors consideration in many automation decisions.

DESIGN AND EVALUATION OF AUTOMATED SYSTEMS

The effect of automated systems on situation awareness and the out-of-the-loop performance problem has been established as a critical issue that can undermine the effectiveness of human-machine performance in advanced systems. Many of the factors that can lead to situation awareness problems — monitoring, passive decision making, poor feedback, poor mental models — can be directly traced to the way that the automated systems are designed. As such, it is possible, and essential, to minimize these problems during system design, thus allowing the potential benefits of automation to be realized without depriving the human operator of the situation awareness needed for good performance.

Interface Design

At a minimum, the design process should include steps to insure that needed information is always present regarding the state of the automation and the state of the parameters being monitored in a clear, easily interpreted format. As subtle changes in the form of information can impact situation awareness, it is critical that proposed designs be tested thoroughly (within the context of the operators' problem domain and in conjunction with multiple task demands) for possible insidious effects on situation awareness. Careful consideration needs to be given to providing interpretable and comprehensible information (that maps to the operator's goals), as opposed to volumes of low level data, in order to better meet operator needs.

New Approaches To Automation

Many of the issues surrounding the negative impact of automation on situation awareness and human performance may be attributable not to automation itself, but the way that automation has traditionally been implemented in many systems. In most cases, the performance of some task has been given over to the automation and the human's job has become that of monitor. New approaches are currently being explored that challenge this division. These approaches redefine the assignment of functions to people and automation in terms of a more integrated team approach. Two orthogonal and possibly complementary approaches can be defined along the axes of Figure 1. One approach seeks to optimize the assignment of control between the human and automated system by keeping both involved in system operation. The other recognizes that control must pass back and forth between the human and the automation over time, and seeks to find ways of using this to increase human performance.

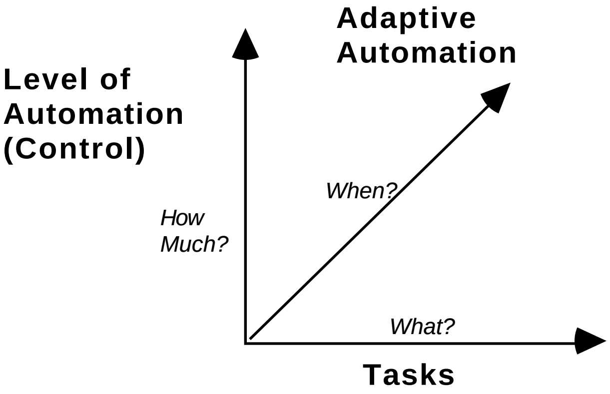

Figure 1 Automation Design Considerations

Level of control. One way to minimize the negative effects of automation is to devise implementation schemes that keep the human actively involved in the decision making loop while simultaneously reducing the load associated with doing everything manually. This can be accomplished by determining a level of automation that minimizes negative impacts on operator situation awareness (Endsley, 1987b; 1993b).

Wiener and Curry (1980) and Billings (1991) have both discussed the fact that automation does not exist in an all or none fashion, but can be implemented at various levels. With regard to the automation of cognitive tasks (through artificial intelligence or expert systems), a task may be accomplished (a) manually with no assistance from the system, (b) by the operator with input in the form of recommendations provided by the system, (c) by the system, with the consent of the operator required to carry out the action, (d) by the system, to be automatically implemented unless vetoed by the operator, or (e) fully automatically, with no operator interaction (Endsley, 1987b; 1993b). This can be viewed as five possible levels of automation from none to full, as depicted in Figure 2.

Endsley and Kiris (in press) implemented automation of an automobile navigation task at each of these five levels. They found that the out-of-the-loop performance problem was significantly greater under full automation than under intermediate levels of automation. This corresponded with a greater decrement in situation awareness under full automation than under intermediate levels, as compared to manual control. By implementing functions at a lower level of automation, leaving the operator involved in the active decision making loop, situation awareness remained at a higher level and subjects were more able to assume manual control when needed.

Thus, even though full automation of a task may be technically possible, it may not be desirable if the performance of the joint human-machine system is to be optimized. Intermediate levels of automation may be preferable for certain tasks, in order to keep human operators' situation awareness at a higher level and allow them to perform critical functions.

		Roles	
Level of Automation		Human	System
None	1	Decide, Act	——
Decison Support	2	Decide, Act	Suggest
Consentual AI	3	Concur	Decide, Act
Monitored AI	4	Veto	Decide, Act
Full Automation	5	——	Decide, Act

Figure 2 Levels of Control and Automation (Adapted from Endsley and Kiris, 1995)

Adaptive automation. Recent work on adaptive automation has also been found to aid in overcoming the out-of-the-loop performance problem (Parasuraman, 1993). Adaptive automation recognizes that over the course of time, control of tasks may need to pass back and forth between an operator and an automated system in response to changing demands. Adaptive automation attempts to optimize this dynamic allocation of tasks by creating a mechanism for determining in real-time when tasks need to become automated (or manually controlled) (Morrison, Cohen, & Gluckman, 1993). In direct contrast to historical efforts which have featured fixed task allocation assignments, adaptive automation provides the potential for improving operator performance with automated systems by continually adjusting to operator needs and keeping operators in the loop. In recent research, Carmody and Gluckman (1993) found Level 2 SA to be impacted by adaptive automation of certain tasks.

Issues. Many questions remain in exploring the problem space set forth by the approach in Figure 1. Most notably, the characteristics of tasks that determine their optimal level of control and suitability for adaptive automation need to be investigated. Gluckman et. al. (1993), for instance, found different effects on workload and performance for adaptive automation involving a static (system monitoring) versus a dynamic (resource management) task. Carmody and Gluckman (1993) also found situation awareness to be more effected by adaptive automation of a dynamic task than a static task. Lewandowski, Durso and Grounlund (1994) have proposed that if parts of an integrated task are automated, more performance decrements will occur than if the whole task is automated. Endsley and Kiris (in press) propose that psychomotor, perceptual and cognitive tasks may be differentially affected by automation level. Considerable work is needed to determine the critical dimensions of tasks for successful implementation of adaptive automation and specifying an optimal level of control for a given task.

Secondly, when adaptive automation should be invoked needs to be determined. In a first look at this issue, Parasuraman (1993) examined whether manual control implemented at a pre-set periodic interval differed in effect from manual control implemented on the basis of poor monitoring performance (indicating a loss of situation awareness). He found no differences between the two conditions in terms of their effect on subsequent human monitoring performance under automation. The insertion of a period of manual control was equally beneficial in both cases. This type of work needs to be extended to address questions of periodic insertion of automation into manual tasks. Research is also needed to explore the interaction between adaptive automation and level of control — how much automation needs to be employed may be a function of when it is employed.

How adaptive automation should be implemented is also a question. Various schemes have been proposed from purely manual control for turning the automation on and off, to system control for invoking automation based on real-time monitoring of human performance, physiology, or flight conditions. This is not a simple matter, however. Many systems have left it up to operators to invoke automation at their discretion. In critical situations however, the operator may be (1) so overloaded as to make this an extra burden, (2) incapacitated or otherwise unable to do so, (3) unaware that the situation calls for automated assistance, or (4) a poor decision maker. Leaving the system with the ability to turn itself on and off may be even more problematic, as this taxes the operator with the task of keeping up with what the system is doing. A major question lies in determining how adaptive automation should be implemented so as to provide the potential benefits without leading to new problems of loss of system awareness.

Thus, an increased level of human control and adaptive automation may provide means for keeping operators sufficiently in-the-loop to avoid the situation awareness decrements that can occur with traditional all-or-nothing function allocations. Significant research issues still need to be resolved to determine how to best implement these concepts within operational settings.

Evaluation of Automated Systems

A direct consideration of the operator interface, the proper level of control for a task, and means of transitioning between automated and non-automated states needs to made during the design process in order to address fundamental problems associated with automation. Although these concepts have shown merit for improving situation awareness, research to establish precise guidelines for such prescriptions is, to date, just beginning. Lacking such guidance, and because the effects of automation can be quite insidious, careful testing during the development of automated systems is imperative.

Several methods have been established for the measurement of situation awareness. (For a complete review see Endsley (1994b).) Most involve the creation of a simulation of the system under consideration. Impact of a particular design concept on situation awareness can be measured directly through either objective or subjective means, or it can be inferred through less direct performance measures.

<u>Objective measurement.</u> The most commonly used means of objectively evaluating a design concept's impact on situation awareness involves directly questioning operators as to their perceptions of critical aspects of the system they are operating. The Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1987a; 1988b) is a technique wherein the simulation is frozen at randomly selected times, the system displays blanked and the simulation suspended while subjects quickly answer questions about their current perceptions of the situation. Subject perceptions are then compared to the real situation based on simulation computer databases to provide an objective measure of situation awareness.

SAGAT includes queries about all operator situation awareness requirements, including Level 1 (perception of data), Level 2 (comprehension of meaning) and Level 3 (projection of the near future) components. This includes a consideration of system functioning and status as well as relevant features of the external environment. This approach minimizes possible biasing of attention, as subjects cannot prepare for the queries in advance since they could be queried over almost every aspect of the situation to which they would normally attend.

SAGAT provides an objective, unbiased assessment of operator situation awareness that overcomes memory problems incurred when collecting data after the fact, yet minimizes biasing of subject situation awareness due to secondary task loading or artificially cueing the subject's attention. Empirical, predictive and content validity has been demonstrated for this technique (Endsley, 1989; 1990a; 1990b).

<u>Subjective measurement.</u> Subjective measures of situation awareness are easier and less expensive to administer than objective measures, but may lack the same degree of accuracy and diagnosticity. The most commonly used method is to have operators provide ratings of their situation awareness with system concepts along a designated scale.

Taylor (1989) developed the Situational Awareness Rating Technique (SART) which has operators rate system designs on the amount of demand on attentional resources, supply of attentional resources and understanding of the situation provided. As such, it considers operators' perceived workload (supply and demand on attentional resources) in addition to their perceived understanding of the situation. While SART has been shown to be correlated with performance measures (Selcon & Taylor, 1989), it is unclear whether this is due to the workload or the understanding components.

<u>Performance measurement.</u> In general, performance measures provide the advantage of being objective and are usually non-intrusive. Simulation computers can be programmed to record specified performance data automatically, making the required data relatively easy to collect. Hansman, et al. (1992), for example, used detection of clearance amendment errors as a measure of aircrew situation awareness in evaluating the use of an automated datalink system for updating the onboard flight management computer. As many other factors can act to influence subject performance measures (such as decision making, workload impacts, actions or individual strategy differences), these are also limited for inferring subject situation awareness by themselves.

General measurement considerations. One of the biggest difficulties associated with automation is its insidious effect on situation awareness and performance. An increased tendency for out-of-the-loop performance problems may be difficult to detect during testing. For this reason, it is preferable to measure situation awareness directly, in addition to evaluating operator performance with an automation concept.

It also needs to be recognized that automation can effect situation awareness in a global, not readily predicted manner. A new system may provide more situation awareness on one factor, but simultaneously reduce situation awareness on others. Assessment of the impact of automation on situation awareness needs to take into account operator situation awareness accross the range of requirements.

Finally, it can take quite a bit of training for operators to feel comfortable with an automation concept and be able to adequately perform with it. Assessments of any automation concept need to be made after operators have become proficient with the system, if a fair evaluation is to be made. Of course, if that proficiency takes an inordinate amount of time (years in the case of previously mentioned aircraft systems), system deficiencies are certainly indicated.

CONCLUSION

In conclusion, the successful implementation of automation is a complex issue. The traditional form of automation which places humans in the role of monitor has been shown to negatively impact situation awareness and thus their ability to effectively perform that function. Losses in situation awareness can be attributed to the unsuitability of humans to perform a monitoring role, assumption of a passive role in decision making, and inadequate feedback associated with automation. As a result many automated systems have been suboptimized, with infrequent, but major errors attributed to a failure of the human component. This unsatisfactory state of affairs currently plagues many automation efforts. New approaches to automation design that seek to fundamentally alter the role of the human operator in interacting with the automated system provide a great deal of promise for surmounting this problem. Careful test and evaluation of proposed automation concepts is imperative for establishing that adequate situation awareness is maintained to keep human operators in the loop and able to fulfill their functions.

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