Situation Awareness: Review of Mica Endsley's 1995 Articles on Situation Awareness Theory and Measurement

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Objective: This article summarizes two articles by Endsley on situation awareness (SA) and presents the influence of the concept on subsequent practice and theory of human factors. **Background:** In her articles, Endsley integrated and consolidated existing research done in the prior decade. **Method:** I carefully examined and integrated subsequent articles on the SA topic written by Endsley and by others. **Results:** This integration revealed that SA has been applied to areas of training, error analysis, design, selection, teamwork, and automation. Some key issues related to automation and SA are reviewed in detail. **Conclusion:** Situation awareness is a viable and important construct that still possesses some controversy over measurement issues. **Application:** Ways in which human factors practitioners have used the SA construct and numerous citations are provided to assist designers.

INTRODUCTION

During the past 15 years, the concept of situation awareness has entered the mainstream of human factors, and the term has certainly entered the vernacular of human factors researchers. This trend reflects, on one hand, the growing extent to which automation does more, and the human operator often does (acts) less in many complex systems but is still responsible for understanding the state of such systems in case things go wrong and human intervention is required (Sheridan & Parasuraman, 2006). On the other hand, the trend reflects the extensive contribution of Endsley's research (Endsley, 1988, 1995a, 1995b, 2006a; Endsley, Bolte, & Jones, 2003; Endsley & Garland, 2001; Endsley & Kaber, 1999) and concept development. This work is embodied in a pair of articles (Endsley, 1995a, 1995b) that I highlight in this special anniversary issue; I also note that this pair appeared in the special issue of *Human Factors* devoted to situation awareness, so by highlighting this pair, I also wish to call attention to the companion articles by other authors in the volume *Human Factors* (1995, 37[1]).

The two articles – "Measurement of Situation Awareness in Dynamic Systems" (Endsley, 1995a) and "Toward a Theory of Situation Awareness in Dynamic Systems" (Endsley, 1995b) – were not "seminal" in the sense of marking the birth of the concept. Indeed, Endsley pays ample heed to more than a decade of work that preceded 1995, citing the work of others (e.g., Fracker, 1988; Weiner & Curry, 1980) as well as her own first paper (Endsley, 1988) as providing foundations for the concept as articulated in 1995. However, the 1995 pair provides an integrated coherent definition of the concept, in the context of other psychological constructs (Endsley, 1995b), and introduces one of the most important measures of situation awareness (Endsley, 1995a), thereby setting the stage for the many recent developments, equally relevant to cognitive psychology (Durso & Gronlund, 1999; Durso, Rawson, & Girotto, 2007) and to the science of human factors (Endsley, 2006b; Tenney & Pew, 2007). It has provided the foundation for five important books on the topic (Banbury & Tremblay, 2004; Endsley & Garland, 2001; Endsley et al., 2003; Garland & Endsley, 1995; Gawron, 2008). Finally, as any important concept should, it has spawned some degree of rigorous academic debate (Dekker & Hollnagel, 2004; Dekker & Woods, 2002). In the following pages, I summarize the highlights of the two articles and, in doing

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so, provide the less familiar reader with a sense of the importance of the construct. I then describe a few important subsequent developments in the field, forecast in Endsley (1995b).

DEFINITIONS AND FUNDAMENTALS

Endsley (1995b) defines situation awareness informally and intuitively as "knowing what's going on" and, more formally, 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" (p. 36). The latter definition appears to have stood the test of time reasonably well and is expressed in highly similar terms by other authors today (e.g., Durso, Rawson, & Girotto, 2007; Tenney & Pew, 2007). Importantly, then, her treatment both "drills down" to the components of this definition and draws back to consider it in a larger context of human performance and cognition.

In drilling down, Endsley draws the careful distinction between the three *levels* of situation awareness (SA) defined by perception (including "noticing"), comprehension, and projection. Clearly, higher levels depend on the success of lower levels. Thus, the air traffic controller may first notice a change in trajectory (or onset of a conflict alert), then comprehend that this means aircraft are now on a converging trajectory (laterally or vertically), and finally understand when, in the future, a conflict may take place and how serious it will be. The diagnostic distinction between these three levels is important, not only because they point to different perceptual/cognitive operations but also because breakdowns in each may have very different consequences for addressing them, through training or system design. For example, a breakdown of Level 1 SA would lead to the design of better alerts. A breakdown of Level 3 SA would lead to incorporation of predictive displays.

Drawing back, Endsley considers the definition in the context of other aspects of human-system interaction and, in so doing, offers the important service of explicitly characterizing what SA is not (exclusions), hence avoiding the pitfalls of merely characterizing SA as "good performance" and thereby also avoiding the creation of a somewhat vacuous concept. These distinctions are important and real both in terms of models of human information processing and characterizations of system behavior. In particular, her writing emphasizes three things that SA is not.

First, SA is not action or performance. That is, the understanding of a situation is quite distinct from the manual or vocal action taken in response to that situation (even if that action is an information-seeking one designed to improve SA). In this regard, the distinction between SA and action is analogous to the classic distinctions in decision theory between state-of-the-world estimation and choice (Edwards, 1961) and, in medicine, between diagnosis and treatment (Garg et al., 2005). Thus, one might say that good SA is generally necessary but not sufficient for good performance. An operator with excellent SA of a failing system may not possess the knowledge of procedures to remedy the failure or may not have the motor execution skills to implement that remedy. In contrast, when automation can support effective performance, is it generally possible to have good system performance manifest in the absence of good SA. As an example here, a pilot who is flying a flight director may be accurately nulling the error symbol (and hence performing well by flying the plane along the desired path) but have very little awareness of where the plane is located over the ground.

Second, SA is not the same as long-term memory knowledge. Here it is important that the construct of SA is primarily applicable only in dynamic situations where variables are changing, typically over the course of seconds or minutes. The definition offered by Durso, Rawson, and Girotto (2007), "comprehension or understanding of a *dynamic* environment" (p. 164), is appropriate here. Hence, static (declarative or procedural) knowledge about the state of the system, characterizing long-term memory, is less directly relevant to the contents of SA, particularly at Level 2. Stated in other terms, the "time constant" of long-term memory (and its associated constructs such as scripts, schemas, and mental models) is in the order of hours, days, and years, whereas the time constant of dynamic system changes, in which SA is the most relevant construct, is in the order of seconds, minutes, or, at most, a few hours. As such, the memory system more closely associated with SA appears to be that of *long-term working memory* (Durso & Gronlund, 1999; Ericsson & Kintch, 1995; Wickens, 2000).

Third, the product of SA is not the same as the process of updating situation awareness. This is a fuzzier exclusion, paralleling the distinction that Adams, Tenney, and Pew (1995) make in the same *Human Factors* special issue between process and product. Two characteristics in particular are essential to the process of maintaining SA. Their discussion illustrates the difficulty of establishing precise boundaries between process and product. (a) Attention (selective attention) directs the acquisition of information essential for Level 1 SA. Indeed, the distinction between process and product at Level 1 is quite fuzzy. (b) Long-term memory is intimately involved with the process of SA updating at all levels. Long-term memory knowledge will direct scanning (Wickens et al., 2008) to support Level 1. Knowledge structures (scripts, schemas, and expectancies) aid understanding and comprehension of the current state via top-down processes, thereby often allowing long-term working memory to replace the more fragile working memory (Durso, Rawson, & Girotto, 2007). Finally, one of the most critical elements for Level 3 prediction is the mental model (Gentner & Stevens, 1983; Wilson & Rutherford, 1989), an agent that, in dynamic systems, can be "run" based on the perceived environmental inputs to project future outputs (Wickens, Gempler, & Morphew, 2000). These aspects of long-term memory can clearly support expertise effects in the process of updating SA. Even here, however, it is possible to make the clear distinction between the learned (over a long time period) properties and rules embodied in the mental model and its more dynamic outputs, reflecting the changing environment (the SA product).

In her article, Endsley (1995b) does a nice job of explicitly outlining the relationship between SA and several other process-related concepts in psychology, such as automaticity, working memory, preattentive processing, perception, confidence, goals, plans, and scripts.

APPLICATIONS OF SITUATION AWARENESS

From the definition of what SA is, and is not, flows a series of important applications addressed in the two articles (Endsley, 1995a, 1995b), and a plethora of research on these areas has followed. These include the following:

Measurement. Endsley (1995a) lays out the criteria for SA measurement, contrasts a series of emerging techniques, and then describes in some detail the SAGAT (situation awareness global assessment technique), which has subsequently become one of the standard instruments. Here participants are intermittently queried, in the middle of a dynamic simulation, about the values of various state parameters in the process under supervision. This query is issued when the display is blanked, so that the operator must rely on working memory to answer the questions. In the first of two experiments, she examines the extent of loss of SA revealed by SAGAT by probing at different time points across several minutes following each blank (see also Gugerty, 1998). In the second experiment, she addresses the critical issue of the extent to which such queries disrupt the process being measured (or disrupt it differentially across different conditions). Importantly, her conclusion, echoed by Pew (2000), is that such interference is minimal (but see the following paragraphs). It is noteworthy that other approaches to SA measurement have been advocated. As one example, the Situation Present Assessment Measure, or SPAM (Durso, Rawson, & Girotto, 2007), assesses the speed of accessing information from a non-blanked display and provides a more sensitive, continuously distributed (time) measure that will be less likely (than SAGAT) to be at floor levels because of memory decay. Comparisons between the two approaches suggest both strengths and weaknesses of each (Alexander & Wickens, 2005). As another example, the loss of SA can be inferred from changes in performance on tasks for which good SA is essential. For example, the freeway driver who pulls into another lane in front of an overtaking car can be inferred to have poor SA. This would be an example of an *implicit* SA measure.

Training. Techniques for training people to maintain good SA through information seeking (Hoffman, Crandall, & Shadbolt, 1998) or teaching predictive skills (O'Brien & O'Hare, 2007) are quite distinct from those that might be applied to training other skills, such as learning procedures or practicing actions (Endsley & Robertson, 2000). Thus, the SA concept is important in allowing greater precision and definition of training requirements.

Error analysis. Often training programs are implemented to remedy a specifically identified problem in human-system interaction. In this regard, SA has served as a tool for accident and incident investigation, revealing the major source of problems. A classic study by Jones and Endsley (1996) has helped to identify Level 1 SA as the dominant source of SA errors in aviation. Corresponding findings have been observed for air traffic control (Durso, Bleckley, & Dattel, 2007), a diagnosis that could directly trigger remedies in alerting system design, as well as attentional training (Gopher, 1992; O'Brien & O'Hare, 2007; Wickens et al., 2008).

Design. As with training, different approaches to

> system design would be taken if the procedures that followed were found wanting than if SA maintenance was inadequate; in the latter case, design would focus heavily on identifying information needs for tasks, as well as the interpretable configuration of these in displays (Endsley et al., 2003). In particular, because of the distinctions between SA and routine performance, the display features to support global SA, necessary in the unexpected circumstances when things go wrong, will need to be substantially different from those that support routine performance in normal operations (Wickens, 2000, 2002). This distinction between normal and abnormal information needs parallels that presented in ecological interface design (Vicente, 2002; Vicente & Rasmussen, 1992).
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> *Prediction.* Situation awareness measures are found to predict and account for added variance in tasks such as air traffic control, above and beyond that accounted for by standard cognitive spatial tests (Durso, Bleckley, & Dattel, 2007; O'Brien & O'Hare, 2007).
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> *Teamwork.* Within a few years following the appearance of the two articles, the issue of team situation awareness emerged as important in understanding team dynamics: What does each worker know about the understanding and workload of the coworker, and how is this supported by interworker communications and technology (Endsley & Jones, 2001)? A critical issue concerns how the concept of "team SA" extends beyond the collective average or sum of SA for the individuals who make up the team (Cooke & Gorman, 2006; Gorman, Cooke, & Winner, 2006; Cooke, Gorman, & Winner, 2007).
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> *Automation and workload.* Arguably the most critical aspect of SA articulated by Endsley (1995b) and further explored in research by Endsley and Kiris (1995), Endsley and Kaber (1999), and Kaber and Endsley (2003) is the intriguing trade-off between workload and situation awareness (Wickens, 2002). Such a trade-off can be expressed in two forms: (a) What are the circumstances in which the two constructs covary in harmony or in opposition? (b) How is this trade-off mediated by the level of automation in human-system interaction? Endsley (1995b) addresses the first issue by identifying the four circumstances, generated by factorial combinations of high and low on each of the two variables, that could occur (see also Endsley, 1993). For example, an increase in workload can divert resources from maintaining situation awareness (hence decreasing the latter), but a well-designed usable display can both reduce workload and increase situation awareness.

Regarding the second of these workload-SA trade-off issues, one of the greatest seeds for important research is provided by Endsley's (1995b) brief treatment of the role of automation levels in mediating the trade-off. This is followed by an important experimental examination of the trade-off in Endsley and Kiris (1995). Of course, the concept of "level of automation" (ratio of automation cognitive and motor "work" to human work, or the degree of authority imposed by automation) predated Endsley's writing and is generally credited to Sheridan and Verplank (1978). Furthermore, it has been elaborated in subsequent treatments by Kaber and Endsley (1997, 2003), Endsley and Kaber (1999), and Parasuraman and colleagues (Parasuraman, Sheridan, & Wickens, 2000; Parasuraman & Wickens, 2008 [this issue]). This research has examined the viability of the straightforward and intuitive assumption that, as the level of automation increases, (a) workload decreases, and (b) situation awareness (of the system controlled by automation) decreases. Here decreased SA is a consequence both of less monitoring of the process that is automated (Level 1 SA) and of the reduced memory for system state, when that state has been changed by another agent (e.g., automation; Level 2 SA; the so-called generation effect; Slamecka & Graf, 1978).

Such a trade-off between two desirable states (high situation awareness and low workload), to the extent that it exists, has major implications for the design of automation, such as that envisioned for the new air traffic control system (*Journal of Air Traffic Control*, 2006; Sheridan, 2007; Wickens, Mavor, Parasuraman, & McGee, 1998). Given that level of automation can be defined on a multilevel ordinal scale, as Endsley and Kiris (1995), following Sheridan and Verplank (1978), have done, then the relationship between level of automation and each component can be of the forms shown in Figure 1.

a. If both functions are essentially linear (Figure 1a), and assuming equal performance by either human or automation, then the "optimum level of SA" can be determined solely on the weighting given by system designers and users to the two constructs, combined with the relative slopes of the two functions.
b. If one or both functions are exponentially increasing (Figure 1b), then the optimum level will typically lie at either high or low ends of the level of automation (LOA) scale.
c. If one or both are logarithmically increasing (Figure 1c), then an optimal LOA typically can be found somewhere in the middle of the scale, with its precise location dependent on the region where the slopes of the two functions are equal.

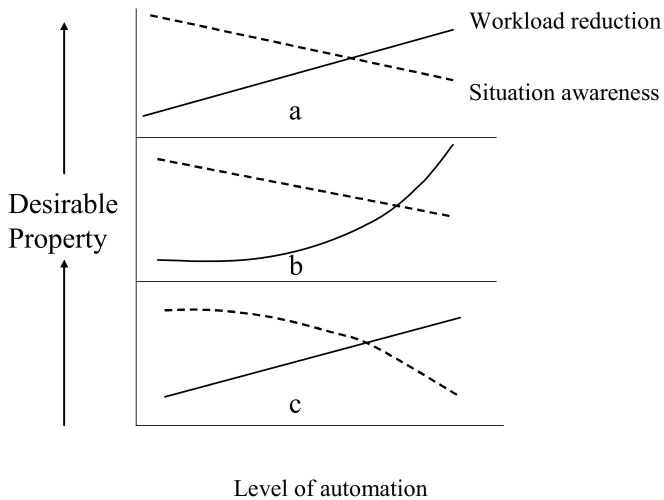

Figure 1. Three examples of two hypothetical functions representing the reduction of workload, as well as the level of situation awareness (SA), as the level of automation is increased. For both variables, high values on the *y*-axis represent good system properties. (a) Both functions are linear. (b) One function is geometrically (or exponentially) changing. (c) One function is logarithmically changing. The text describes the implications for each case for assessing the optimal level of automation.

The nature of these two functions is clearly an empirical question, and Endsley and Kiris (1995) appear to have been the first to systematically address this issue, in the context of an in-vehicle decision support system for navigation. Their data in that study appeared to establish a nonlinearity in Level 2 SA and hence pointed to an intermediate LOA as optimal. Their data, however, were not overly clear-cut and so provided an instigation for further research on this all-important topic. Here again, subsequent studies by Kaber and Endsley (1997, 2003; Endsley & Kaber, 1999), addressing the same conceptual issue, in the context of different tasks, have revealed only partially satisfactory answers, generally favoring intermediate levels of automation as optimizing the trade-off (and hence suggesting the nonlinearities of one or both functions as in Figure 1c) but also revealing that the behaviors of the individual functions are not always consistent from one application to another (e.g., where there are changes vs. constancies between adjacent levels of automation). Thus, although this important design issue has not been clearly resolved by the existing research, the work has established a clear "paradigm" in complex system research – and one expressed at a sufficiently generic level as to be applicable in areas such as health care, highway driving, flying, and process control.

CRITICISMS OF SITUATION AWARENESS

Criticisms of the SA concept can be conceptually distinguished as belonging to two categories. In the first of these are criticisms, or at least complementary views to Endsley's approach, that nevertheless have embraced the concept of situation awareness. Key among these is the focus on differences in measurement discussed earlier (e.g., SPAM; Durso, Rawson, & Girotto, 2007) and whether more naturalistic techniques such as implicit measures of SA are more appropriate. Also, as noted earlier, the distinctions between SA and long-term memory remain fuzzy, in part because SA can be applied to constructs, such as weather, that may change over relatively long time constants (hours and days). In the second category are those who question the very validity and viability of the SA construct altogether (e.g., Dekker & Hollnagel, 2004; Dekker & Woods, 2002) as providing an unnecessary construct above already existing elements such as attention. To this, one can speak to the increased use of the construct in both theory and applications as testimony to its viability, as well as note that such strong criticism is also an index of the value of the SA concept to human factors science. This, as any science, will advance only through vigorous debate, and both critics and advocates of SA have continued to keep this debate healthily alive (Parasuraman, Sheridan, & Wickens, 2008, in press).

CONCLUSION

The concept of situation awareness lies at the heart of the intersection between basic cognitive psychology and the applied science of human factors. The two articles reviewed here, as well as the vast amount of Endsley's other research, represent a critical contribution within which a growing body of research was integrated and served to stimulate a productive and useful corpus of human factors conclusions and further research. As automation continues to be imposed in human work environments, there is little doubt that the interest in how SA may degrade or be supported will continue to grow.

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