Special Issue

# Situation Awareness Misconceptions and Misunderstandings

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Situation awareness (SA) has become a widely used construct within the human factors community, the focus of considerable research over the past 25 years. This research has been used to drive the development of advanced information displays, the design of automated systems, information fusion algorithms, and new training approaches for improving SA in individuals and teams. In recent years, a number of papers criticized the Endsley model of SA on various grounds. I review those criticisms here and show them to be based on misunderstandings of the model. I also review several new models of SA, including situated SA, distributed SA, and sensemaking, in light of this discussion and show how they compare to existing models of SA in individuals and teams.

**Keywords:** situation awareness, sensemaking, working memory, situation assessment, team situation awareness

Situation awareness (SA) theory, design, training, and measurement have formed a substantive portion of the human factors research field over the past 25 years. Although the SA construct was initially met with skepticism by some (Flach, 1995), the intervening years have found that SA research has taken hold in the cognitive psychology and human factors fields, forming a fundamental paradigm shift. For example, Lee, Cassano-Pinche, and Vicente (2005) examined the impact of papers published in *Human Factors* between 1970 and 2000. Four of the top 10 cited papers published from 1990 to 1995 were on SA, and one received 50% more citations in the 5 years following its publication than any other paper published in the 30-year time period of the review. Patrick and Morgan (2010) found some 17,500 articles discussing SA in a Google Scholar search, with almost all of the papers falling after 1988 and a sharp increase following the 1995 special issue of *Human Factors* on SA. The interest in SA grew quickly from its initial start in aviation to many disparate fields including air traffic control, military operations, transportation, power systems, law enforcement, emergency management, health care, space, transportation, education, mining, and oil and gas operations.

Wickens (2008) provides an overview of significant research on SA and its progress in areas of measurement, training, error analysis, team work, automation, and workload, finding that its increased use in both theory and applications is testimony to its viability as a construct. Tenney and Pew (2006) and Durso and Gronlund (1999) also provide reviews of this popular construct. In addition, Endsley and Jones (2012) review much of the extensive research in the field and use this as a basis for a detailed process and guidelines for the design of systems to support SA and for the development of advanced training programs to enhance the cognitive processes and mechanisms that underlie high levels of SA.

The construct is not without its detractors, however. For example, Dekker and Hollnagel (2004) have complained that SA is a "folk model" without detail or scientific basis. Parasuraman, Sheridan, and Wickens (2008) soundly discredited that argument, showing a strong body of empirical research on the topic, its diagnosticity with regard to human states, its prescriptive usefulness, and its theoretical and empirical distinction from performance and other mental constructs.

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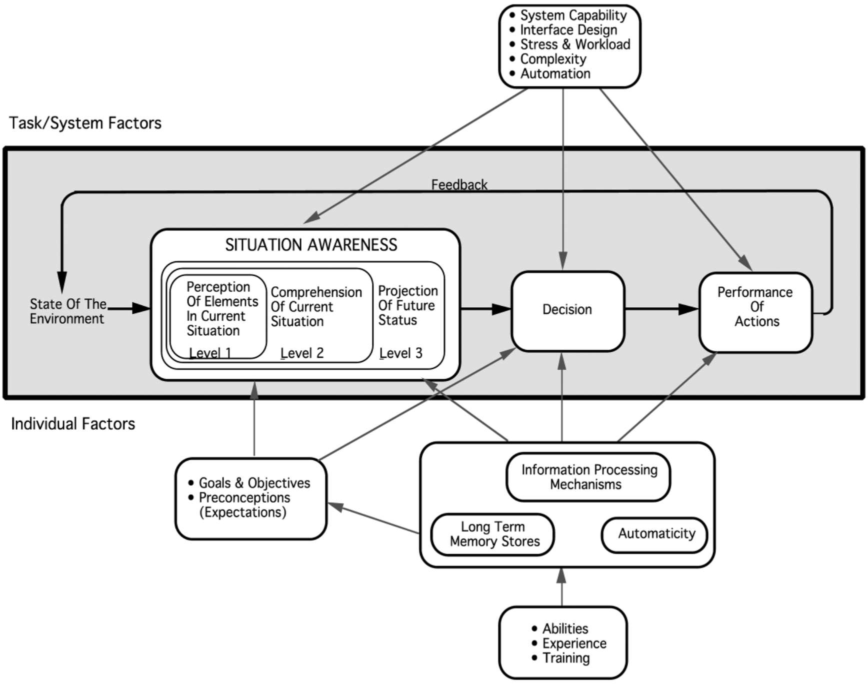


*Figure 1.* Model of SA in dynamic decision making (Endsley, 1995).

Despite such reassuring conclusions, the research literature has recently seen new critiques of the prominent theoretical models of SA that are unfortunately largely based on misunderstandings or misconceptions regarding these models and the research that supports them. First, I will briefly review the Endsley (1995) model of SA (hereafter referred to as the Endsley 1995 Model) at which much of that criticism has been directed, discussing points of confusion that have emerged. Following this, I will review several new models that have been offered to overcome the stated limitations.

## ENDSLEY 1995 MODEL OF SA

Several models of SA have been introduced (Adams, Tenney, & Pew, 1995; Durso & Gronlund, 1999; Smith & Hancock, 1995), each with many similarities in terms of their focus on the importance of goals, memory structures, mental models, and attention (see Endsley, 2000b, for a detailed review). The Endsley 1995 Model has generally been considered one of the most extensive and highly cited models of SA (Golightly, Wilson, Lowe, & Sharples, 2010; Wickens, 2008). As portrayed in Figure 1, this model consists of several key factors:

- perception, comprehension, and projection as three levels of SA;
- the role of goals and goal-directed processing in directing attention and interpreting the significance of perceived information;
- the simultaneous role of information salience in "grabbing" attention in a data-driven fashion;
- the importance of alternating goal-driven and data-driven processing in processing information in the environment;
- the role of expectations (fed by the current model of the situation and by long-term memory stores) in directing attention and interpreting information;
- the heavy demands on limited working memory restricting SA for novices and for those in novel situations, but the tremendous advantages of mental models and pattern matching to prototypical schema that largely circumvent these limits;
- the use of mental models for directing attention to relevant information, providing a means for integrating different bits of information and comprehending its meaning (as relevant to current goals),

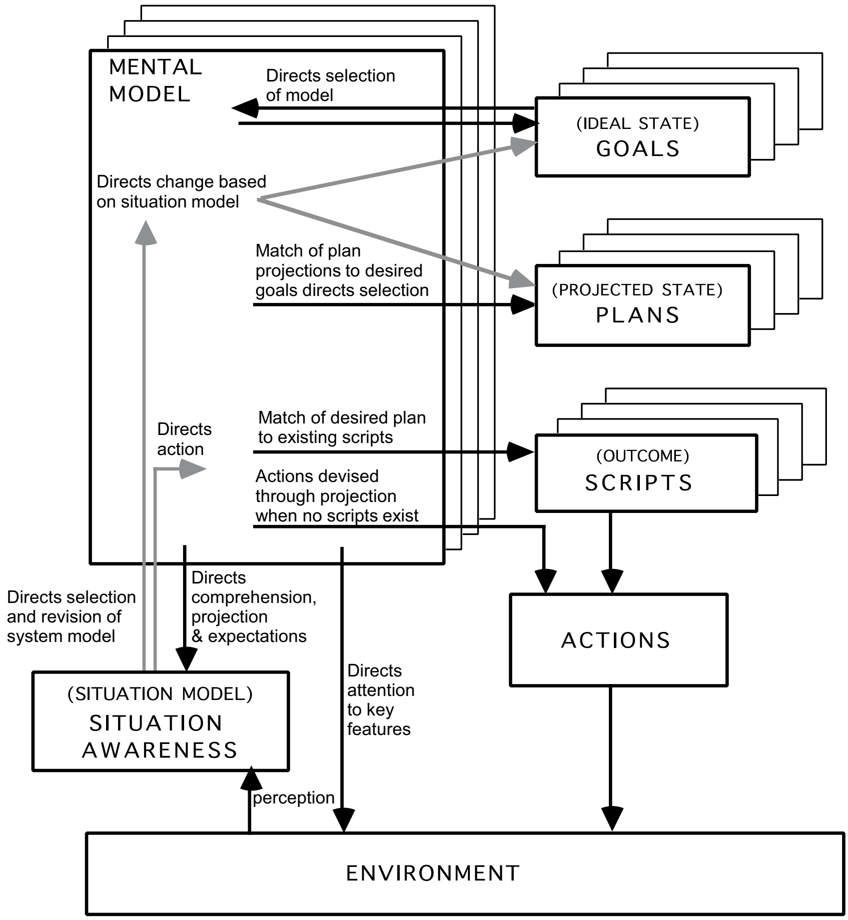


*Figure 2.* Relationship of goals and mental models to SA (Endsley, 1995).

and allowing people to make useful projections of likely future events and states;

- the use of Q-morphisms in mental models to provide defaults, providing reasonable SA with even limited and missing information, and a context model providing for the representation of uncertainty in the situation representation;
- a process for building and updating mental models over time;
- pattern matching to schema, prototypical states of the mental model, that provide rapid retrieval of comprehension and projection for the recognized situation through critical cues and, in many cases, providing single-step retrieval of appropriate actions for the situation;
- the role of automaticity on SA;
- people as active participants in the development of their own SA, based on how they direct their attention, communicate with team mates, and manipulate their tools to search for desired information;
- an ongoing dynamic process of gathering and interpreting information to update the situation model and using that situation model to search for information until decisions can be made;
- a linkage between goals and mental models that drives the development or selection of plans and scripts for directing actions, the use of the activated mental model to direct attention to the environment to feed into the constantly updated situation model, and use of the situation model in updating the selection of the mental model to be active (Figure 2);
- the role of environmental, task, and system factors in SA, including the capability of systems for deriving needed information; the effect of

system complexity on SA; the effectiveness of the user interface for providing rapid access and understandability of needed information; the role of stressors, workload, and fatigue on SA mechanisms and processes; and the effect of automation on SA; and
- an error taxonomy, based on this model, that characterizes the underlying factors that can lead to SA errors in perception, comprehension and projection.

Some early general (and reasonable) criticisms of the model concerned its overall breadth, the degree to which its constituent components are well understood, and its testability. It should be noted that this is a framework model, built on the foundation of many well-researched constructs in the field of cognitive psychology. Given the critical evolutionary importance of SA for surviving in a hostile environment and for finding food and game, I think it unsurprising that so many cognitive mechanisms and complex interactions would underlie such a fundamental precursor to decision making. Although some people have felt this to be a disadvantage of the model, I actually think it is a strength. The considerable detail in the model makes it possible to leverage existing research to provide a great deal of understanding and guidance regarding this complex process.

The criticism has also been made that some of the underlying constructs in the model are themselves not well understood (e.g., mental models and schema) (Smith & Hancock, 1995). The original 1995 paper, and subsequent articles that provided additional clarification on it (Endsley, 2000b, 2004), endeavored to provide clear definitions of these constructs, to discuss how the mental models form and evolve and how they work within the SA process, and how they relate to each other (e.g., how goals and mental models interact in directing attention and forming action selection). In addition, by drawing on these constructs, new insights have been created, allowing SA research to provide an operational mechanism for better defining the mental model itself (Endsley, 2000a; Zhang, Kaber, & Hsiang, 2010). As research in cognitive science progresses and such constructs become even better understood, this will in turn better inform our understanding of SA.

Although it may be difficult to test the model as a whole, excellent research has been conducted to test and extend various aspects of it, including:

- the roles of working memory and long-term memory (Endsley & Bolstad, 1994; Gonzalez & Wimisberg, 2007; Gutzwiller & Clegg, 2012; Sohn & Doane, 2004; Sulistayawati, Wickens, & Chui, 2011),
- the mechanisms behind projection (Horswill & McKenna, 2004; Jones, Quoetone, Ferree, Magsig, & Bunting, 2003),
- individual characteristics affecting SA abilities (Caretta, Perry, & Ree, 1996; Durso, Bleckley, & Dattel, 2006; Endsley & Bolstad, 1994; Gugerty & Tirre, 2000; O'Brien & O'Hare, 2007; Sulistayawati et al., 2011),
- the role of automation on SA (Carmody & Gluckman, 1993; Endsley & Kiris, 1995; Jones, Strater, Riley, Connors, & Endsley, 2009; Kaber & Endsley, 1997a, 2004; Riley et al., 2008; Sarter & Woods, 1995), and
- the relationship between SA and workload (Bolstad & Endsley, 2000; Endsley, 1993a; Endsley & Rodgers, 1998; Wickens, 1992).

This research has served to confirm many aspects of the model and to extend our understanding of it. More importantly, the model has provided a rich set of guidelines for improving the design of systems to support SA in individuals and teams and to improve programs to enhance SA through training, which is what it was intended to do (Endsley & Jones, 2012).

## SA FALLACIES

Several recent publications have lodged a number of criticisms of the model based on certain fallacies or misunderstandings of it. This has created some unnecessary confusion. I will discuss each of these claims and show why they are inaccurate in their representation of the Endsley 1995 Model of SA.

### Fallacy 1: The Three Levels of SA Are Linear

In some cases, the three levels of SA in the model have been characterized as strictly linear.

For example, Sorensen, Stanton, and Banks (2010) incorrectly state that the Endsley model requires a person to have Level 1 and 2 SA in order to have Level 3: "Endsley et al. (2003) argue that without a sound development of levels 1 and 2, the individual cannot achieve level 3 SA" (p. 453). Salmon, Stanton, and Young (2012) and Dekker and Lutzhoft (2004) similarly claim that it is a strictly linear model, and Chiappe, Strybel, and Vu (2011) characterize the model as serial.

This characterization is unfortunately inaccurate and misunderstands the model. The three levels of SA represent *ascending levels of SA*, not linear stages. A person who understands the current situation has better SA than one who can read the data on a screen but does not know what it means. Similarly, a person who can project the likely future events and states of the system and environment has better SA than one who cannot:

> This does not mean that projection, comprehension and projection necessarily occur in linear discrete stages. In fact, the model clearly states that this is not necessarily the case. … The reality, however, is that a simple 1-2-3 progression (data driven) is not an efficient processing mechanism in a complex and dynamic system, which is where expertise and goal driven processing come into play. (Endsley, 2004, p. 319)

The Endsley 1995 Model shows that, in addition to a strictly forward, data-driven perception to comprehension to projection flow, people also make heavy use of goal-driven processing. Based on their goals and current understanding and projections (Level 2 and 3 SA), they may look for data to either confirm or deny their assessments or to fill in gaps (i.e., search for relevant Level 1 data). "This is an iterative process, with understanding driving the search for new data and new data coming together to feed understanding, as represented by the feedback arrow in the model in Figure 1" (Endsley, 2004, p. 319).

The Endsley 1995 Model also specifies "defaults" in the mental models that are used to fill in where Level 1 data are not known, based on current comprehensions or projections (Level 2 and 3 SA):

> Default values for certain features of a system can be used if exact current values are not known. Fighter pilots, for example, usually get only limited information about other aircraft. They therefore must operate on default information (e.g. it is probably a MIG-29 and therefore likely traveling at certain approximate speed). When more details become available, their SA becomes more accurate (e.g. knowledge of the exact airspeed), possibly leading to better decisions, but they are still able to make reasonable decisions without perfect information. (Endsley, 1995, p. 45)
>
> That is they use their level 2/3 SA to generate assumptions regarding level 1 representations (either rightly or wrongly). In this way people can have level 2 and 3 SA, even when they do not have complete or accurate level 1 SA, and can use the higher levels of SA to drive the search for and acquisition of level 1 SA. (Endsley, 2004, p. 318)

As shown in Figure 3, the model is in no way strictly linear with regard to the three levels of SA.

As a corollary to this assertion, Salmon et al. (2012) also state the following: "Further, little consideration is given to the links and interactions between SA elements and the individual's cognizance of them. The linkage between elements could conceivably determine the character of SA as much as the elements themselves" (p. 484). This also is an inaccurate representation of the model. "Based on knowledge of Level 1 elements, particularly when put together to form patterns with the other elements (gestalt), the decision maker forms a holistic picture of the environment, comprehending the significance of objects and events" (Endsley, 1995, p. 37). Comprehension (Level 2 SA) is all about the meaningful integration (i.e., linkages) of the disparate data taken in from the environment, as filtered though their relevant goals. Comprehension is formed by putting two and two together to get four. It is

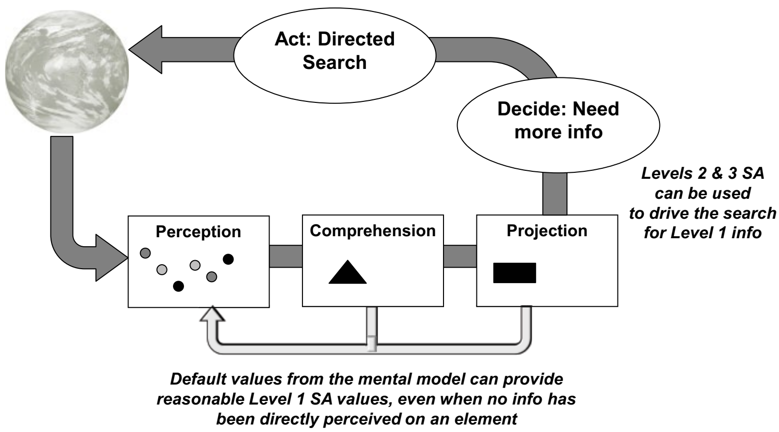


*Figure 3.* Higher level SA can be used to drive the search for data and to provide default values when information is not available.

understanding that if pressure and volume change, then so would temperature, based on the dynamics of the system that dictates the relationships between these variables, for example.

Salmon et al.'s criticism may be related to the degree to which the Situation Awareness Global Assessment Technique (SAGAT) measures SA of the various elements, without specifying the linkages between them. However, because such linkages are generally determined through deeply imbedded mental models and schema, people would be very poor at articulating the detailed nature of those links (Nisbett & Wilson, 1977), and that is not the point of such a measure.

Sorensen et al. (2010) further state that the three levels of SA in the model are somehow highly separated: "For these experts, it is not possible to divide their SA into the three levels in a meaningful way. The model does not explain situations where SA is a continuous process" (p. 453). This is also a mischaracterization of the model. Experts do not necessarily divide up their understanding of the world into these neat and tidy categories. In fact, most of my experience in working with experts in a wide variety of fields shows that their perceptions, comprehensions, and projections are fairly tightly integrated, as would be predicted by the mental models that underlay them. "While the three levels of SA are general descriptions that aid in thinking about SA, at times, definitively categorizing an SA requirement into a particular level will not be possible" (Endsley, Bolte, & Jones, 2003). The definition of SA is descriptive of the types of information contained within the construct. Neither it nor the more detailed model of SA claim that such information is mentally segregated into such categories.

## Fallacy 2: The Model Is a Data-Driven Information-Processing Model

Other critiques characterize the Endsley 1995 Model as being a linear, data-driven information-processing model. Salmon et al. (2012) state the following: "A linear feedback model, the three-level model does not deal with the notion that SA can be as much a feed-forward phenomena as a feedback one" (p. 483). Chiappe et al. (2011), characterizing the Endsley 1995 Model as an information-processing model, reject it as an example of "linear applications of the information-processing approach, which hold that perception precedes cognition and action follows it, making perception and action peripheral processes that are not essential to understanding cognition" (p. 629).

These characterizations are also inaccurate. "SA presents a level of focus that goes beyond traditional information-processing approaches in attempting to explain human behavior in operating complex systems" (Endsley, 1995, p. 32). Although the model incorporates many of the same cognitive processes and mechanisms as traditional information-processing models, it very clearly features the importance of goal-driven processing in understanding the processes by which SA occurs: "In what Casson (1983) has termed a *top-down decision process*, a person's goals and plans direct which aspects of the environment are attended to in the development of SA" (p. 47). A detailed process is described, linking the individual's goals to the activation of mental models for guiding the search for and interpretation of information and to plans for achieving those goals.

The model also describes how changes in the environment (bottom-up processing) can affect a switch in active goal states. "SA is largely affected by a person's goals and expectations which will influence how attention is directed, how information is perceived, and how it is interpreted. This top-down processing will operate in tandem with bottom-up processing in which salient cues will activate appropriate goals and models" (Endsley, 1995, p. 49).

The Endsley 1995 Model of SA is neither limited to data-driven processing nor is it strictly linear:

> Essentially, human information processing in operating complex systems is seen as alternating between data driven (bottom-up) and goal driven (top-down) processing. This process is viewed as critical in the formation of SA (Endsley, 1988, 1995). … Dynamic switching between these two processing modes is important for successful performance in many environments. (Endsley, 2000b, p. 15)

In a related critique, Klein, Phillips, Rall, and Peluso (2007) state that "our approach differs from Endsley in that she is describing how people notice and make inferences about data, whereas we assert that people use their frames to define what counts as data in the first place" (p. 120). They make the point that people are active in determining what is relevant. This too is not different than the Endsley 1995 Model, which describes the important role of the mental model in directing attention to gather the needed information.

> When an individual has a well-developed mental model of the behavior of particular systems or domains, the model will provide (a) for the dynamic direction of attention to critical cues, (b) expectations regarding future states of the environment (including what to expect as well as what not to expect) based on the projection mechanisms of the model, and (c) a direct, single-step link between recognized situation classifications and typical actions. (Endsley, 1995, p. 44)

> Different problem framings can induce different information integration (situation comprehension), and this determines the selection of a mental model to use for solving the problem. Thus it is not only the detailed situational information (Level 1 SA) but also the way the pieces are put together (Level 2 SA) that direct decision strategy selection. (Endsley, 1995, p. 40)

Thus, it can be seen that the Endsley 1995 Model also emphasizes the active role that people play in obtaining their own SA.

> It is critical to note that this is not a passive process of receiving displayed information, but one in which the operator may be very actively involved. For instance, the operator in many systems can control which information is displayed (e.g. through menu selection) and which information is attended to. They may also be able to control which information the system collects by sending out commands to get certain information from linked systems or by setting the direction and coverage of the sensors, for example. People are therefore very active participants in the situation assessment process, with SA guiding the process and the process resulting in the SA. (Endsley, 2000b, p. 8)

The Endsley 1995 Model shows a very dynamic process, with goals, activated mental models, and current situation representations driving the active search for information, operating in conjunction with an alternating bottom-up data-driven process. People are active participants in the search for information in terms of how they allocate their attention and in terms of how they set up the environment, systems, and communications mechanisms to form information flows from their systems and their teammates.

### Fallacy 3: The Product Versus Process Distinction

Much has been made of a false dichotomy between SA as a process and SA as a product. In the early days of discussion on SA, it became evident that researchers were miscommunicating with each other on what they meant when they used the term SA. Some used it to mean the processes that people were using to gather and understand their world, and some were using the term to describe the resultant, constantly evolving situation model that was derived from that process. Accordingly, the editors of the special issue of *Human Factors* in 1995 on SA asked its authors to disambiguate the terms in their discussions in order to provide better clarity for the readers. As a result, I distinguished to two in accordance with common usage in the aviation community. "As a matter of consistent terminology, it is first necessary to distinguish the term *situation awareness*, as a state of knowledge, from the processes used to achieve that state. These processes, which may vary widely among individuals and contexts, will be referred to as *situation assessment* or as the process of achieving, acquiring, or maintaining SA" (Endsley, 1995, p. 36). I continue to use this terminology today.

Surprisingly, some people have used this statement to claim that the Endsley 1995 Model only addresses SA as a state and not as a process, even though there are 24 journal pages describing in detail the various processes and cognitive mechanisms used to arrive at SA. Salmon et al. (2008), for example, state that "the three level model depicts SA as a product separate from the processes used to achieve it" (p. 303). Klein et al (2007) state that their model of sensemaking is different from the SA model because they are "interested in sensemaking as a process and not just a state of knowledge" (p. 116). They assert that "Mica Endsley's work on situation awareness is about the knowledge state that's achieved—either knowledge of current data elements, or inferences drawn from these data, or predictions that can be made using these inferences. In contrast, sensemaking is about the process of achieving these kinds of outcomes, the strategies, and the barriers encountered" (Klein, Moon, & Hoffman, 2006b, p. 71). Chiappe et al. (2011) also criticize the Endsley 1995 Model, claiming it is not possible to distinguish process from product.

Given the detailed descriptions of the processes involved in getting and maintaining SA provided in the Endsley 1995 Model and the extensive descriptions on how the current situation representation guides the search for and interpretation of information to integrate into that representation, it is inaccurate to claim that this model does not address SA processes or that it does not show the two as being clearly intertwined. "A person's SA will in turn have an effect on what information is searched out and attended to, with product affecting process in a circular fashion" (Endsley et al., 2003, p. 25)

As stated originally, "I am full in agreement with Adams, Tenney and Pew … that there is great benefit from examining the interdependence of the processes and the resultant state of knowledge, however, in order to clarify discourse on SA, it is important to keep the terminology straight" (Endsley, 1995, p. 36). In fact, both of these models (Adams et al., 1995; Endsley, 1988, 1995) discuss the processes involved in achieving and maintaining SA as a state of knowledge (as a product of those processes) and the ways in which the current product affects those processes in turn.

### Fallacy 4: The Model of SA Is Not Cyclical or Dynamic

Related to the process versus product distinction, some critiques have characterized the Endsley 1995 Model as not dynamic (Salmon et al., 2008). Salmon et al. (2008) write that "the model has also been criticized for its inability to cope with the dynamic nature of SA. Uhlarik and Comerford (2002) state that the process of achieving SA presented by the three-level model is both static and finite … the description of the way in which SA dynamically modifies interaction with the world and then interaction with the world dynamically modifies SA is logical and goes beyond the static perspective taken by Endsley's model" (pp. 305-306).

In contrast, however, the Endsley 1995 Model shows a dynamic feedback loop for gathering information and acting on the environment. A person's SA is updated on an almost ongoing basis in most dynamic environments (unless they are asleep or unvigilant):

> The dynamic aspect of real-world situations is a third important temporal aspect of SA. The rate at which information is changing is a part of SA regarding the current situation, which also allows for projection of future situations (Endsley, 1988, 1995c). The dynamic nature of situations dictates that as the situation is always changing, so the person's situation awareness must constantly change or be rendered outdated and thus inaccurate. (Endsley, 2000b, p. 6)

The Endsley 1995 Model focuses on the role of time and the temporal aspects of the situation as important to SA, reflecting substantially on dynamics:

> First, although SA has been discussed as a person's knowledge of the environment at a given point in time, it is highly temporal in nature. That is, SA is not necessarily acquired instantaneously but is built up over time. Thus it takes into account the dynamics of the situation that are acquirable only over time and that are used to project the state of the environment in the near future. So although SA consists of an operator's knowledge of the state of the environment at any point in time, this knowledge includes temporal aspects of that environment, relating to both the past and the future. (Endsley, 1995, p. 38)

The effects of the situation dynamics (e.g., current rate of change, projections of future changes) are an integral part of their SA.

Often a critical part of SA lies in understanding how much time is available until some event occurs or some action must be taken. The "within a volume of space and time" contained in the definition of SA pertains to the fact that operators constrain the parts of the world (or situation) that are of interest to them based on not only space (how far away some element is), but also how soon that element will have an impact on the operator's goals and tasks. Time and system changes over time are strong parts of Level 2 SA (comprehension) and Level 3 SA (projection of future events).

Thus, the Endsley model incorporates the importance of a dynamic ongoing cycle of gathering, interpreting, and projecting information. It depicts a very dynamic process employed within very dynamic worlds, forcing SA to be constantly changing as well in order to stay accurate and up-to-date.

## Fallacy 5: The SA Model Fails to Take Into Account Meaning

Dekker and Lutzhoft (2004) describe the Endsley SA model as only dealing with mere low-level stimuli: "Information processing theories begin with the primitive, meaningless nature of stimuli in the world (they are 'elements' in the words of one SA theory)" (p. 25). On the contrary, there is nothing primitive or meaningless about even Level 1 SA, much less the higher levels. The elements of SA in the definition are analyzed in detail for each domain as a critical research step (Bolstad, Riley, Jones, & Endsley, 2002; Connors, Endsley, & Jones, 2007; Endsley, 1993b, 1999; Endsley, Farley, Jones, Midkiff, & Hansman, 1998; Endsley & Robertson, 1996; Endsley & Rodgers, 1994; Matthews, Strater, & Endsley, 2004). Such analyses are conducted with subject matter experts in the domain, who provide a clear indication of what they consider meaningful. Even Level 1 data tend to consist of clearly observable, meaningful pieces of information, and higher level comprehension and projection are certainly higher order assessments that are a deep reflection of "meaning" for that person. For examples, see Table 1.

It should be noted that the elements defined for a given domain and operational role take into account the full range of the aspects of the situation that are relevant to the decision maker—the technical system, the outside environment (e.g., weather, terrain), the state of other actors (e.g., location of other aircraft, actions of enemies and civilians in a military action), and the state and status of teammate activities (e.g., the level of workload and abilities of one's co-pilot, the location

**TABLE 1:** Examples of Perception, Comprehension, and Projection Elements for Different Domains

| Domain | Perception | Comprehension | Projection |
|---|---|---|---|
| Commercial Aviation Pilot | Airport location, altitude | Impact of aircraft malfunction on aircraft performance | Projected trajectory own aircraft and others |
| | Approach in use | Impact of weather on flight plan | Predicted wind sheer |
| | NOTAMS | Time available to perform tasks | Predicted changes in visibility |
| | Taxiway width and conditions | Risk of hazard to passengers/crew | Projected separation |
| | Traffic on taxiway/runway | Effectiveness of anti-ice measures | Projected schedule deviation |
| | System failures/degrades | Ability to reach alternate airport | Projected impact of changes on safety of flight |
| | Heading, altitude | Compliance with requirements | Projected fuel requirements |
| | Airspeed, pitch and roll attitude | Taxiway suitability | Projected time available on fuel remaining |
| | Terrain location, height | Ability to reach destination | Projected areas of severe weather |
| | Weather, areas and altitudes effected | Validity of indications | Projected schedule deviation |
| | Special use airspace activation | Confidence in crew members | Predicted duration of hold |
| | Clearances | Cost/benefit of change | Projected areas of turbulence |
| Military Commander | Enemy disposition | Advantages/disadvantages of course of action (COA) | Projected ability of plan to meet mission objectives |
| | Weather | Areas of cover and concealment | Projected time required to carry out COA |
| | Terrain | Impact of weather on plan | Projected risk/safety of troops |
| | Type/capabilities of threats | Impact of weather on visibility/weapons | Projected ability to obtain information |
| | Resources available | Available fields of fire | Projected ability to communicate |
| | Experience level of troops | Ability to support plan | Projected help needed by adjacent brigades |
| | Readiness level of troops | Risk of mission failure/success | Projected impact of weather on planned COA |
| | Friendly losses | Risk of casualties/loss of equipment | Projected ability to support plan |
| | Civilian disposition | Ability to counteract enemy actions | Projected actions of enemy |
| | Friendly location and status | Ability to mitigate risk | Projected actions of civilians |
| | Weapons and ammo | Impact of deviations on mission | Projected impact of enemy COA |
| Power Grid Operator | Elements out of service | Cause of limit violation | Projected impact on system of adjusting reactive power |
| | Changes in flow | Amount of load shed needed | Projected loads |
| | Line voltage | Time available to solve problem | Projected impact of problem on other utilities |
| | Direction of flows | Imbalance in loads between regions | Credibility of projected violations |
| | Load levels | Confidence level in parameter value | Potential for voltage collapse |
| | Available generator units and capacitors | Cause of variations in load | Most likely projected violations |
| | Temperature at element | Cause of variations in output | Most significant projected violations |
| | Current limits | Confidence in problem identification | Solution with projected minimal impact |
| | Scheduled outages | Effected organizations | Projected impact on system of adding/removing element |
| | Linkages between systems | Exceedence of normal/emergency limits | Projected distance to voltage collapse |
| | Current system topography | Options available | Projected change in voltage on lines with drop at location |

*Note.* NOTAMS = Notices to Airmen.

and plans of other team members). It is not constrained to any one subset of this information.

The elements to be perceived, the comprehensions that are needed, and the projections to be made can be carefully defined with subject matter experts in the domain who provide a clear indication of what they consider meaningful using a goal-directed task analysis (GDTA) process (Endsley & Jones, 2012). Such analyses form a strong foundation for subsequent research in each domain, for developing valid metrics of SA, and for designing improved systems and training programs. Thus, the concept of meaning is foundational to SA. The Endsley 1995 Model, coupled with a methodology to determine what is meaningful for a given operational role, provides a valuable contribution beyond mere discussions of meaning that do not also provide needed structures for researchers and designers to determine what is meaningful as a key input to the design process.

## Fallacy 6: SA Is All Contained in Working Memory

In some cases, the Endsley 1995 Model has been characterized as representing SA as exclusively held in working memory (Chiappe, Rorie, Moran, & Vu, 2012; Chiappe et al., 2011; Chiappe, Vu, & Strybel, 2012). "According to Endsley et al. (2003), mental models differ from situation models. The former are held in long-term memory and are relatively static, whereas the latter constitute our SA and are held in WM" (Chiappe, Rorie et al., 2012, p. 3). "SA includes information at three different levels—perception, comprehension, and projection—that is synthesized into a detailed, stable, situation model consciously held in WM (Endsley et al. 2003)" (Chiappe, Rorie et al., 2012).

This is an incorrect representation of the Endsley 1995 Model, which describes working memory as a bottleneck only for novices and those in novel situations and that in practice long-term memory structures obviate such limitations. "Where they have been developed, long-term memory stores, most likely in the form of schemata and mental models, can largely circumvent these limits by providing for the integration and comprehension of information and the projection of future events (the higher levels of SA), even on the basis of incomplete information and under uncertainty" (Endsley, 1995, p. 49). The Endsley 1995 Model depicts a more integrated relationship between the sort-term working memory and long-term memory systems on which SA relies. "To view SA as either a function of working memory or long-term memory would probably be erroneous" (Endsley 2000b, p. 11).

To investigate the possible dependence of SA on working memory, Endsley (1990) provided pilots with SAGAT queries in random order following multiple freezes in the simulation to determine whether accuracy on a given SA query declined as a function of time, as would be predicted if SA were held strictly in working memory. The study showed that pilots were as accurate in answering SAGAT queries 5 to 6 minutes following the freeze, as compared to right after the freeze, showing no memory decay as would be expected with information stored solely in working memory.

Endsley (1990, 2000b) concluded that this result supported a model of cognition that shows working memory to be an activated subset of long-term memory (Cowan, 1988), as shown in Figure 4. In this model, information proceeds directly from sensory memory to long-term memory, which is necessary for pattern recognition and coding. Those portions of the environment that are salient remain in working memory as a highlighted subset of long-term memory through either localized attention or automatic activation. In this way, information from the environment may be processed and stored in terms of the activated mental model or schema (i.e., it provides the current situation values of these more abstract models). Thus activated, these schema provide a rich source of data for bringing to bear on the situation including mechanisms for processing the data (i.e., forming Level 2 and Level 3 SA) and default values for filling in missing information.

This is consistent with many other researchers. Durso and Gronlund (1999) came to a similar conclusion, drawing on a model by Ericsson and Kintsch (1995) in which pointers in working memory point to information stored in long-term memory. Adams et al. (1995) also discuss pointers from working memory to long-term

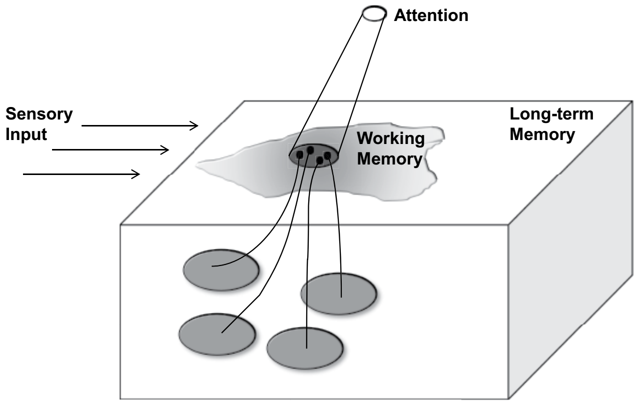


*Figure 4.* Working memory as an activated subset of long-term memory (Endsley, 2000b).

memory, and Sarter and Woods (1991) emphasize the importance of information that can be activated from long-term memory to support limited working memory.

Additional research supports the position that SA is not contained in nor constrained by working memory for those with experience. Sohn and Doane (2004) found that expert pilots rely more on long-term memory for SA than on working memory, and only their novice pilots were working memory constrained. Sulistayawati et al. (2011) showed that experienced pilots with lower working memory spans were able to perform just as well as those with better working memories on SAGAT questions in their study. Endsley and Bolstad (1994) also found that working memory ability did not predict SA scores in experienced pilots, and Gonzalez and Wimisberg (2007) showed that Level 1 SA improved over time with experience on a task, and its relationship to working memory decreased accordingly.

Gutzwiller and Clegg (2012) examined the role of working memory on SA, using a simulated task with student subjects, and found no relationship between working memory and Level 1 SA, but a positive relationship with Level 3 SA, which the Endsley 1995 Model states is highly demanding, even for experts, unless such predictions can be automatically accessed from schema. "Prediction of future states (the culmination of good SA) imposes a heavy load on working memory by requiring the maintenance of present conditions, future conditions, rules used to generate the latter from the former, and actions that are appropriate to the future conditions" (Endsley, 1995, p. 43). These studies all support the Endsley 1995 Model, which states for experienced operators SA is not constrained by working memory (nor uniquely contained in it), but rather draws on long-term memory as well for its representation.

## Fallacy 7: The SA Model Only Represents a Cartesian "In-the-Head" View of the World and Does Not Encompass the Wider Sociotechnical Environment

Dekker, Hummerdal, and Smith (2010) states that "situation awareness research typically follows the Cartesian tradition that sets the mind against the world and that maintains that it is meaningful to examine a mind independently of that world (e.g. Endsley 1995)" (p. 132). This view is echoed by Salmon, Stanton, and their colleagues, who maintain that the Endsley 1995 Model (as well as most other SA research) can be characterized as an "in the mind" view point (Salmon et al., 2008; Sorensen et al., 2010; Stanton, Salmon, Walker, & Jenkins, 2010; Stanton et al., 2006). They contrast this with engineering approaches that represent SA as all in the systems, and a third approach that considers SA to be a function of both the human and the system.

The Endsley 1995 Model, however, describes the contribution of both characteristics and mechanisms of both the individual and of task and system factors on SA. In particular, the capabilities of the system for gathering needed information, of the system interface for presenting that information effectively, the effects of stress and workload, the complexity of the system, and the characteristics of automation are all significant factors affecting SA that are discussed in detail in the model. In addition, the model emphasizes the importance of context to decision making:

> The situation parameters or context of a problem largely determines the ability of individuals to adopt an effective problem-solving strategy. It is the situation specifics that determine the adoption of an appropriate mental model, leading to the selection of problem-solving strategies. In the absence of an appropriate model, people will often fail to solve a new problem, even though they would have to apply the same logic as that used for a familiar problem. (Endsley, 1995, p. 39)

Thus, it is not strictly an "in the head" model, divorced from the situations and contexts in which people find themselves. On the contrary, the Endsley 1995 Model argues that context matters a great deal for human decision-making and provides a detailed discussion of the ways in which that occurs.

The extant research on SA over the past 25 years has devoted considerable attention to studying many of these sociotechnical factors and to testing and examining how they affect SA and how they can be improved. Likewise, most SA research has been conducted in highly realistic and rich simulation environments or in actual domain settings with experienced decision makers. This has included research with pilots, air traffic controllers, military commanders, soldiers, and power plant operators, to name a few.

Characterizations that the Endsley 1995 Model (and most other research in the domain) focuses only on what is going on in the head or is divorced from the "situations" it seeks to study fail to recognize the degree to which SA research considers tasks and context as it focuses on experts working within complex, dynamic, and realistic settings. The vast majority of SA research has studied not only awareness but also the factors of the situations that are embodied in SA and the characteristics of those environments that affect it. A significant body of research findings leading to improved design of those systems has resulted from this work (Endsley & Jones, 2012).

## RECENT MODELS OF SA

Recently, a few newer models related to SA have been published in the literature, presented as remedies for the above fallacies. In some cases, the new models provide a characterization of SA that is different than existing models, but in many cases, they also provide explanations that are quite similar, confusing the situation. I will address these models individually.

### Situated SA

Chiappe and colleagues have promoted a model they call "Situated SA" (Chiappe, Rorie et al., 2012; Chiappe et al., 2011; Chiappe, Vu et al., 2012).

> The situated SA approach holds that operators maintain their understanding of dynamic situations by relying on minimal internal representations and engaging in frequent interactions with a structured environment. Operators sample limited amounts of information from the environment in cycles, and extract its relevance by combining it with an easily accessible context, as per RT [relevance theory]. (Chiappe et al., 2011, p. 18)

They propose this theory based on several of the previously discussed fallacies, most notably that established models of SA are "Cartesian" in-the-head models; are limited by linear, information-processing theory (Fallacies 1, 2, and 7); and provide a false distinction between process and product (Fallacy 3). Their primary rationale for the Situated SA model, however, is that they feel it is necessary in order to represent how people overcome the limitations of working memory. This overarching premise, that SA must be limited by working memory, is not supported, however, as was demonstrated in Fallacy 6.

Although working memory is a bottleneck for novices or those in novel situations, as shown in the earlier discussion of Fallacy 6, numerous studies support the Endsley 1995 Model in showing that SA is not limited by working memory in most cases involving skilled performance and most likely benefits from an integrated working memory and long-term memory system. Thus, the Situated SA model, which stipulates that only limited information constituting SA is held in working memory at any one time, separated from long-term memory that cannot hold SA in their view, fails to accurately represent cognitive performance in the majority of experts on which SA research is focused. (Note, this does not mean that I am saying that people incorporate all information into their situation representation, just that which is relevant to maintaining their model of what is happening in the situation.)

Therefore, the need for the Situated SA model that keeps most SA "off-board" becomes negated in practice. Chiappe, Rorie et al. (2012) note that "for off-loading to be a reliable cognitive strategy, individuals must incorporate the external representations into their operations in a way that increases the likelihood of successful performance" (p. 7). Although operators can and often do create heuristics and reminders in their work environment to assist them in keeping up with information and their task status, in my view these work methods and cues do not constitute SA nor substitute for it. The sheer volume of information to be acquired and the mental processing associated with higher levels of SA, requiring accesses to deeper mental constructs, could not be adequately explained by the limited numbers of off-loading techniques available.

Chiappe, Rorie et al. (2012) dismiss the role of mental models, schemata, and scripts for minimizing working memory load because they feel the dynamic information comprising SA could not be a part of long-term memory (LTM). However, the research cited here disputes that view. SA of dynamic information by experts is clearly available far beyond the time limits associated with working memory without typical decay effects (Endsley, 1990). And expert SA in a large number of studies is found to diverge from working memory capacity (Gonzalez & Wimisberg, 2007; Gutzwiller & Clegg, 2012; Sohn & Doane, 2004; Sulistayawati et al., 2011). The Cowan (1988) model, which integrates working memory and LTM structures, provides for such a finding. If SA is thought of as a highlighted current state of the mental model, it makes mentally retaining SA of complex systems and situations feasible, as observed in many expert performers.

This actually is the primary limitation of the Situated SA model. Information that exists in the environment (in displays, the natural world, or other artifacts) but of which the operator is not aware (due to other attentional demands, out-of-the-loop problems, poor interfaces, hidden screens, interference effects, etc.) does not constitute SA. It is by definition information of which he or she is not aware (hence the opposite of SA).

The constraint to hold all SA in working memory imposed by the Situated SA model more closely represents the performance seen of novices who have no mental models in long-term memory to rely upon, which has been shown to result in very poor SA (Endsley, 2006). If people actually could hold only very limited amounts of information in their internal situation model, they would need to exercise excessive rates of information sampling and still would fail, as working memory would be inadequate for holding and integrating all the relevant information in the dynamic and complex domains where SA is important. The Endsley 1995 Model provides a detailed discussion of how mental models and goals direct effective information sampling and attention in the face of heavy data overload, overcoming working memory limitations that would exist without such mental models, and provide mechanisms for determining relevance and the meaning of information. It shows that expert SA has access to long-term memory stores in an integrated working memory and long-term memory system that overcomes working memory limitations.

Chaippe et al. (2011) also propose that Relevance Theory (RT) is needed because they claim other models fail to describe how information relevance for guiding attention is determined. The Endsley 1995 Model, however, provides a detailed discussion on how mental models and goals serve the function of defining relevance. Whether or not RT provides additional explanatory power to the issue of information relevance is open to debate. Although the logic provided (i.e., relevant information is that which is beneficial and yields conclusions that matter to the individual) is certainly inarguable, I am not sure that it provides additional benefits to our understanding of SA. First, it does not provide an a priori way to determine what will be relevant for a given individual. In contrast, users of the Endsley 1995 Model have been able to use GDTAs to determine in advance what types of information are relevant for any given operator and apply that to better design information systems for providing it in useful ways. The goal-driven behaviors, and the mental models that serve them, provide the structures for determining a priori what will be relevant and useful for addressing the various goals and decisions for which a given operational role is responsible. Thus, although RT states a definition for what is relevant, it does not clarify the cognitive mechanisms used to determine relevance, nor does it provide the means to determine a priori what will be relevant to decision makers to better design the systems they need.

The second aspect of RT theory states that people will use minimal effort to acquire and process information. This may be true in general, although there are also many instances where people will exert extra effort to obtain additional confidence in some piece of information. That is, they may double-check information, acquire a second source to cross-check it, or confer with others to raise their confidence or trust in some piece of information, all of which require additional effort. How confident people are in their SA has consistently turned out to be important in many operational domains (from aviation to military commanders to power grid operators). If one assumes that the degree of information reliability is a part of relevance, then one can certainly make the case that this supports taking extra effort to obtain that information. At this point, it is unclear how much additional predictive power RT provides for determining information relevance for SA.

## Sensemaking

*Sensemaking* is a term popularized by Weick (Weick, 1995; Weick, Sutcliffe, & Obstfeld, 1999) that is focused on how people work to make sense of the information and situations in which they find themselves, largely at the organizational level with respect to explaining organizational accidents or unusual events. Thus, it is largely retrospective in nature. Although some people have tried to claim that sensemaking is different than SA, Weick actually references the Endsley 1995 Model for his description of how SA functions at the individual cognitive level, focusing more at the organizational level in his work.

Sensemaking is basically "the process of forming level 2 SA from level 1 data through effortful processes of gathering and synthesizing information, using story building and mental models to find some representation that accounts for and explains the disparate data" (Endsley, 2004, p. 324). There are some similarities and some differences between SA and sensemaking.

(1) Although SA is sometimes derived through a conscious deliberative process to form an understanding of what is going on, it is also often based on a highly automatic process of situation recognition, using schema of prototypical situations, that is dynamic and ongoing, whereas sensemaking is characterized as primarily of the conscious deliberative type. For instance, Kaempf, Klein, Thordsen, and Wolf (1996) found 87% of decision cases involving tactical commanders were characterized by fast, reflective situation recognition, as opposed to deliberative storybuilding. In this sense, the Endsley 1995 Model captures the deliberative sensemaking processes, as well as additional processes that are used in more fluid decision making. "A combination of pattern-matching, conscious analysis, story building, mental simulation, and meta-cognitive processes all may be used by operators at various times to form SA" (Endsley, 2000b, p. 15).

(2) Sensemaking is generally backward looking, whereas SA is forward looking. Sensemaking focuses on forming reasons for past events and diagnosing the causative factors for observed faults, which is certainly important given Weick's focus on understanding problems in organizations. Although SA incorporates such assessments as a part of comprehension (e.g., alarm diagnosis and the cause of perceived cues are examples captured as Level 2 SA requirements in analyses), it also focuses on understanding how

these factors influence other aspects of the situation and projections of the future.

For example, a doctor would determine that anaphylactic shock (comprehension) is the underlying cause of observed low blood pressure and urticaria (perceptions), possibly due to exposure to a previously administered drug to which the patient was unknowing allergic (Schulz, Endsley, Kochs, Gelb, & Wagner, 2013). She might make this assessment using a deliberative process where multiple possibilities are considered, or she might immediately leap to this conclusion based on pattern matching the cues perceived with prototypical situations involving anaphylactic shock from memory. Whether or not a conscious deliberative process is used depends largely upon whether a successful pattern match that satisfies the individual is made quickly (based on the presence and mental availability of sufficiently similar schema). Whereas sensemaking focuses on only the more deliberative of these two possibilities, SA theory includes both the deliberative and reflexive, automatic case.

(3) Although sensemaking ends with whatever explanations it derives, SA theory also includes how people use those diagnoses and explanations to inform their fuller understanding of the situation (e.g., how the anaphylactic shock is likely to be affecting other organs and vital signs, such as heart rate and respiration) and their projections of likely future events, such as the potential for respiratory failure and circulation failure unless an epinephrine injection is provided immediately. Thus, SA is also focused on the effects of events on the rest of the system and the ongoing projection and decision cycle that occurs in dynamic decision making.

Sensemaking therefore focuses on a subset of the processes involved in SA. It does not present any unique cognitive processes or aspects from the perspective of cognitive psychology. Klein and his colleagues (Klein, Moon, & Hoffman, 2006a; Klein et al., 2007), however, have recently introduced a Data-Frame model of sensemaking. Klein et al. (2007) claim that this model is different from the Endsley 1995 Model of SA on several dimensions.

First, in comparison to the Endsley 1995 SA model, they state that they are interested in "sensemaking as a process and not just a state of knowledge" (Klein et al., 2007, p. 120). This has been shown to be a false distinction in Fallacy 3—the Endsley 1995 Model deals extensively with the processes involved in developing SA. Second, they state the following: "Our approach differs from Endsley in that she is describing how people notice and make inferences about data, whereas we assert that people use their frames to define what counts as data in the first place" (Klein et al., 2007, p. 120). This also is a false distinction, as demonstrated in Fallacy: The Endsley 1995 Model describes extensively how mental models, goals, and schema drive the search for data and the integration of that data into meaningful assessments. Klein et al.'s use of frames to organize and direct attention to critical information provides essentially the same the role as the mental models in the Endsley 1995 Model, inducing information search, interpretation, and integration. Thus, the sensemaking model is not different from the Endsley 1995 SA Model in these two respects.

Third, Klein et al. (2007) claim their model is different in that "sensemaking is more than an accurate retrieval of information and inferences. Sensemaking is directed at performing functions such as … problem detection, problem identification, anticipatory thinking, forming explanations, seeing relationships as well as projecting the future (which is level 3 of Endsley's model)" (p. 119). However, the Endsley 1995 Model deals extensively with these issues as well.

Problem detection and identification are often a significant part of situation comprehension. Klein et al. (2007) use the example of weather forecasters needing to determine which are the significant storms they need to track for the day. Similarly, Endsley (1995) shows that comprehension and projection often focus on detecting and identifying critical problems: "An air traffic controller needs to put together information on various traffic patterns to determine which runways will be free and *where there is a potential for collisions*. An automobile driver also needs to detect *possible future collisions* in order to act effectively, and a flexible manufacturing system operator needs to predict *future bottlenecks and unused machines* for effective scheduling" (p. 37).

Such problem identification and detection assessments frequently come up in analyses of

Level 2 and 3 SA requirements, which include things like (1) infantry platoon leaders—likelihood of enemy and attack, vulnerability to enemy fire, and impact of weather on ability to carry out a mission (Matthews et al., 2004); (2) pilots—impact of malfunctions on safety of flight, deviation of altitude from terrain, and sufficiency of fuel to reach destination (Endsley, Farley et al., 1998); (3) air traffic controllers—impact of weather on flight safety, impact of malfunctions on communications, impact of aircraft requests on separation and safety, amount of separation between aircraft (Endsley & Rodgers, 1994); (4) power grid operators—areas of load imbalance, system limit violations, need for load shedding (Connors et al., 2007); and (5) weather forecasters—level of threat associated with weather conditions (Jones et al., 2003). These assessments are clearly the key indicators for problem identification and detection, which constitute many of the key decisions that show up in GDTA analyses of SA requirements.

Forming explanations and seeing relationships is of course much of what comprehension (Level 2 SA) is all about. "Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. … Based on knowledge of Level 1 elements, particularly when put together to form patterns with the other elements (gestalt), the decision maker forms a holistic picture of the environment, comprehending the significance of objects and events" (Endsley, 1995, p. 37).

Comprehension requirements in a given domain are based on the integrated lower level data, showing the "so what" of the information that determines its relevance. Relationships and explanations within the data form a key component of these comprehensions. Common comprehension items (1) directly compare Level 1 elements (e.g., deviation from planned, deviation from limits, conformance to clearances, deviations from correct system settings), (2) form assessments based on integrations of Level 1 elements (e.g., distance available on fuel, distance to next turn on route, immediacy of threat, vulnerable areas, confidence level in information, coverage areas), (3) determine priorities (e.g., highest priority threat, highest priority alarm, highest priority weather events), and (4) form an understanding of the impact of Level 1 items on other aspects of the system or relevant goals (e.g., impact of weather on terrain passability, impact of event on mission, impact of hazard on safety, airworthiness of aircraft). These types of elements are detailed in the specific GDTA analyses of SA requirements in each domain.

Anticipatory thinking is also discussed in the Endsley 1995 Model in numerous ways. It includes preconceptions and expectations as a significant factor in the model that influence (1) how attention is directed, (2) speed and accuracy of perception, (3) the role of expectations in interpreting perceived information, and (4) the role of violated expectations in selecting new mental models and in modifying mental models, goals, and plans.

> The main clue to erroneous SA will occur when a person perceives some new piece of data that does not fit with expectations based on his or her internal model. When a person's expectations do not match with what is perceived, this conflict can be resolved by adopting a new model, revising the existing model, or changing one's goals and plans to accommodate the new situation classification. If the new data can be incorporated into the model, this may merely indicate that a new prototypical situation (state of the model) is present that calls up different goals and plans accordingly. If the new data cannot easily fit into the existing model, the model may be revised. A common problem is whether to continue to revise the existing model to account for the new data or choose an alternate model that is more appropriate. For the latter to occur, something about the data must flag that a different situation is present. (Endsley, 1995, p. 57)

The model also includes a discussion of how such expectations are formed, including mental models, prior experiences, instructions, or other communications.

Other types of anticipatory thinking are also a part of Level 3 SA. The importance of projecting the future is emphasized throughout the model, providing a means for proactive decision making.

I have also emphasized the importance of contingency planning for forming high levels of SA in a wide variety of domains, including aviation, driving, medicine, and military operations (Endsley, 1993b, 1995, 2006; Endsley et al., 2003; Endsley & Robertson, 2000b). "Contingency planning greatly contributes to high levels of SA projection (the highest level of SA) and the ability to quickly detect and comprehend events. Pilots who do not actively engage in contingency planning are far more likely to be overloaded by events in high workload periods" (Bolstad, Endsley, Howell, & Costello, 2002, p. 22).

Therefore, "problem detection, problem identification, anticipatory thinking, forming explanations, seeing relationships, as well as projecting the future" are all heavily incorporated within the Endsley 1995 Model and research based upon it. Although I certainly believe there is ample room for increased research and expanded models on these topics, SA clearly plays a role in them, and claims that the SA model does not address them are overstated.

So how then is the Klein et al. Data-Frame model of sensemaking actually different than the Endsley 1995 Model of SA? First, they clearly state that their sensemaking model is only focused on deliberate efforts to understand events. It therefore does not apply to the more dynamic, rapid, and automatic situation assessment type behavior associated with dynamic systems that the Endsley 1995 Model also covers.

Table 2 provides a side-by-side comparison of various features of the two models. Although Klein et al. (2007) discuss their model in terms of frames rather than mental models, these two concepts are really analogous. They denote a frame as "an explanatory structure that defines entities by describing their relationship to each other" (Klein et al., 2007, p. 118). They define stories, maps, scripts, and plans as types of frames, in the sense that these types of structures can be used to think about and organize information.

In comparison, the Endsley 1995 Model describes mental models as "mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (Rouse & Morris, 1985, p. 7). The mental model provides "(a) knowledge of the relevant elements of the system that can be used in directing attention process, (b) a means of integrating the elements to form an understanding of their meaning (level 2 SA), and (c) a mechanism for projecting future states of the system based on its current state and an understanding of its dynamics (level 3 SA)" (Endsley, 1995, p. 43). The model also provides for "schemata linked to the mental model which are coherent frameworks for understanding information, encompassing highly complex system components, states and functioning" (Endsley, 1995, p. 43), and scripts as special cases of schemata. In this regard, it too is an explanatory structure that defines the relationships between elements.

In viewing Table 2, it is apparent that the idea of a frame is analogous to the concept of a mental model in explaining sensemaking behaviors and provides no new or conflicting views of this process compared to the Endsley 1995 Model. The Data-Frame model of sensemaking, however, does not explain many aspects of cognition that the Endsley 1995 Model does, including how such mental models or frames are developed and modified, how they are linked to goals and plans, how they support active replanning, how expectations or preconceptions are developed and affect the process, and the many task, system, and environmental factors that can affect the process.

Most importantly, however, this model of sensemaking tries to separate the conscious deliberative type of situation understanding from that which happens rapidly and automatically in so many cases. Although that might make sense at one level, the reality is that, in many situations, the recognition of *when one needs to use a more deliberative process to understand the situation is in itself a significant part of the process.* That is, most of the time people are using the rapid situation recognition pattern matching type process that characterizes recognition-primed decision making (Klein, 1993). This is seen in experts of many types—pilots, air traffic controllers, drivers, system operators, power grid operators, managers, and

**TABLE 2:** Comparison of Endsley 1995 Model of SA to Data-Frame Model of Sensemaking

| Model Components | Endsley 1995 Model of SA | Klein et al. 2006a Model of Sensemaking |
|---|---|---|
| Attention to data | Mental models determine what data are attended to, how they are combined, how they are integrated and interpreted | Frames determine what are meaningful data, shape how data are acquired and represented |
| Integration of data | Mental models determine information integration to provide meaning; defaults in the mental model are used to fill in missing data and direct the search for more details | Elaborating the frame—process involves adding to the frame, relationship among data |
| Misrepresentations of data | Representational errors can occur in which people stick with inaccurate mental models, explaining away data that do not fit | Preserving the frame—people may try to explain away data to fit the frame |
| Data fitting | Pattern matching of data to available models used to select model, switch models | Questioning the frame—detect inconsistencies, anomalies, judge plausibility, data quality; selecting new frames that better fit the data |
| Mental models for processing | The use of mental models to interpret and integrate the data to form understanding | The use of mental models (backward looking) to process beyond what is presented |
| Model selection | Selection of appropriate mental model or schema based on a few critical cues, also may be goal driven | Frame may be inferred from a few key features (anchoring) |
| Mental simulation for projections | The use of mental simulation as well as pattern matching to schema for future projections | Mental simulation (forward looking) |
| Expertise | Novices lack mental models and schema that are used by experts | Experts and novices reason the same way, but experts have more frames |
| Development of models | Based on training and experience; learning of categorization and transition functions, model refinement process for developing mental models and creating new ones; Q-morphisms for defaults; inclusion of confidence levels and uncertainty | Not described |
| Link to goals | Goals can drive mental model selection, information integration, and interpretation; linkage between goals and mental models specified | Not described |
| Link to plans | Role of goals, SA, and mental models in development and modification of plans described | Not described |
| Expectations | Formation of expectations and their effect on information interpretation | Not described |
| Task/system effects | Includes stressors, fatigue, workload, system design, interface design, and automation | Not described |
| Types of decision processes | Both automatic pattern matching for SA and conscious deliberative situation assessment are considered; role of automaticity described | Conscious deliberative situation assessment only |
| Dynamic processing | Role of top-down and data-driven processing, and attention switching | Not described |

physicians. A key activity is recognizing that the situation cues presented do not really match well or clearly to existing schema or models and that the person needs to consider alternate possibilities for what is going on or may happen. By trying to divorce the deliberative process from the more automatic process, this key aspect of skilled decision making is lost.

The Endsley 1995 Model of SA provides for SA as it exists in dynamic decision making, with the full range of mechanisms used for situation assessment, interpretation (sensemaking), and projection as well as the linkage between situation representation and plans and actions, and addresses how the situation representation directs the attention and interpretation processes. A more complete representation of sensemaking is provided in the Endsley 1995 Model, including how the underlying mental models and schemata are developed and modified and the ways in which the automatic and deliberative types of processes fit together.

## Team SA

Thus far, the discussion has focused almost exclusively on cognitive models of SA at the individual level. Much work over the past 20 years also has been conducted on the SA of teams. *Team SA* has been defined as "the degree to which every team member possess the SA needed for his or her job" (Endsley, 1995, p. 39). In this sense, it means that each member of a team needs to have the SA he or she need for his or her specific duties in order for the team to be successful. It is not sufficient if one person in the team has the needed SA, but that information is not successfully transmitted to another team member who needs it, as a critical error can result.

A related concept, *shared SA*, is defined as "the degree to which team members have the same SA on shared SA requirements" (Endsley & Jones, 2001, p. 48). In this definition, team members do not need to share everything they know, which would constitute overload, but only those informational needs that they have in common, as a function of their overlapping goals. Endsley and Jones (2001) and Endsley and Jones (2012) describe a detailed process for determining the overlapping SA requirements that need to be shared among any two or more team members through a comparison of the GDTAs that lay out their individual SA requirements.

Bolstad et al. (2002), for example, show how shared SA requirements are determined by comparing the different SA requirements of two different military staff officers (intelligence and logistics). They show that although many Level 1 SA elements needed by these two roles are the same, they actually have very different comprehension needs associated with the data. They also have many Level 1 SA requirements that are different from each other. Some of their Level 3 SA projection needs are the same and some are different. Therefore, supporting shared SA in such a team would require ensuring that the correct Level 1 information is provided to each team member and that shared SA information provided across team members includes not only consistent and correct information on the Level 1 SA items in common but also many shared projections that would affect their decision making, helping to keep them on the same page.

Salas, Prince, Baker, and Shrestha (1995) provided a model of team SA that shows it as comprised of both individual SA and team processes. Endsley and Jones (2001) developed a more detailed model of Team SA, Figure 5, that depicts the critical factors that will impact the quality of Team SA. This model includes:

(1) Team SA Requirements—including sharing of the Level 1, 2, and 3 SA elements that are in common across team members, the status of other team members' tasks on oneself, the status of own tasks on others, the impact of one's actions on others and vice versa, and projections of the actions of other team members. This information is all pertinent to the ability of the team to coordinate its actions.

(2) Team SA Devices—The model lays out many devices that may be used by teams to form Team SA. This includes communications (both verbal and nonverbal), shared displays (visual displays, auditory or other displays), and information perceived directly by the individuals by being in a shared environment. In many cases, only a subset of these devices may be present, funneling information sharing into a narrow bandwidth (e.g., verbal communications).

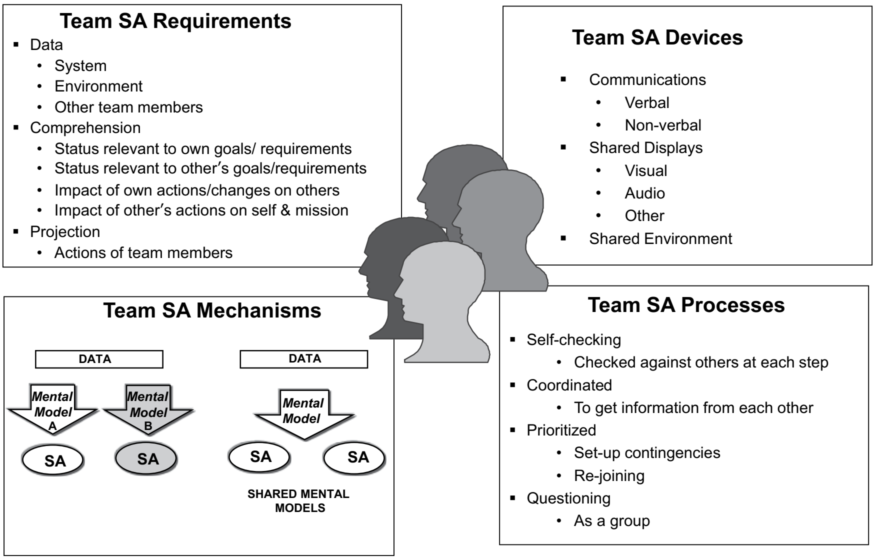


*Figure 5.* Model of Team SA (Endsley & Jones, 2001).

Bolstad and Endsley (2000) found that when new devices are introduced (e.g., shared visual displays), there can be a significant shift in reliance on other devices, showing that people make tradeoffs between them.

(3) Team SA Mechanisms—Teams are not solely reliant on direct information sharing through SA devices, however, but also can benefit from the presence of certain mechanisms that facilitate the development of shared SA. Specifically, shared mental models have been shown to improve the degree of shared SA in teams (Bolstad & Endsley, 1999; Cannon-Bowers, Salas, & Converse, 1993; Stout, Cannon-Bowers, & Salas, 1996). Orasanu and Salas (1993) describe the ways in which shared mental models can be developed. Jones (1997) found that 44% of aircraft accidents happen on the first leg of the first day when a captain and first officer initially fly together as a team, when good shared mental models may have not yet been developed. Mosier and Chidester (1991) found that teams with shared mental models needed less verbal communications. Thus, shared mental models, when they exist and are accurate, can facilitate the development of shared SA in teams, reducing dependence communication and other shared SA devices.

(4) Team SA processes—a great deal of research has been done to describe the effective (and ineffective) processes used by teams to form SA (Chidester, Kanki, Foushee, Dickinson, & Bowles, 1990; Cooke et al., 2003; Endsley & Robertson, 2000a; Orasanu, 1990, 1995; Orasanu & Salas, 1993; Prince & Salas, 1993, 1998; Prince, Salas, & Stout, 1995; Taylor, Endsley, & Henderson, 1996). Although this literature base is too extensive to summarize here, it is important to point out that the processes teams use to interact and share information are critical to the development of good individual SA and shared SA within teams.

Over the past 20 years, a substantial body of research has investigated how SA is formed (or not formed) in teams, methods for determining shared SA requirements across team members, and a determination of how to best support SA in team operations through the design of shared displays and their features (Endsley et al., 2003; Endsley & Jones, 2012). This work has been applied to aviation, maintenance, military, and power grid operations teams who are co-located and many who are distributed. Endsley and Jones (2001) define Distributed SA (DSA) as "SA in teams in which members are separated by distance, time and/or obstacles." They point out that, despite these challenges, the SA needs of the team members are the same as when they are collocated, but are made much more difficult to achieve as many shared SA devices (e.g., non-verbal communications, shared displays, shared mental models) may not be present.

## DSA

The Endsley and Jones 2001 Team SA Model needs to be contrasted with another recent theory called DSA being promoted by Salmon, Stanton, and colleagues (Salmon et al., 2008; Salmon et al., 2012; Sorensen et al., 2010; Stanton et al., 2010; Stanton et al., 2006; Stanton, Harrison, Taylor-Burge, & Porter, 2000). This model is quite different than the DSA described above in that it depicts SA as being distributed in the world. That is:

> in looking at the construct of SA in this manner, it is assumed that the team's awareness of the situation is distributed throughout the joint system comprising team members and the artifacts that they are using. No one member has the overall SA, rather it is distributed around the system. The main difference between individual and team models of SA and DSA approaches relate to the treatment of SA as a cognitive construct or as a systems construct. Individual and team models suggest that SA exists in the mind of individuals, whereas DSA approaches view SA as an emergent property or a product of the system itself. (Salmon et al., 2008, p. 313)

The rationale provided for the DSA model is largely pinned on an inaccurate understanding of the Endsley 1995 Model of SA, as discussed earlier, including:

- Fallacy 1: The three levels of SA are linear.
- Fallacy 2: The model is a data-driven information-processing model.
- Fallacy 3: The product versus process distinction.
- Fallacy 4: The model of SA is not cyclical or dynamic.
- Fallacy 6: SA is all contained in working memory.
- Fallacy 7: The model only represents an "in the head" view of the world and does not encompass the wider sociotechnical environment.

Each of these claims has already been shown to be incorrect. In addition, while primarily discussing a model of SA that occurs among distributed teams, these statements refer almost exclusively to models of individual SA for comparison and mostly ignore existing team SA models and the extensive research on team SA conducted by myself and others.

After discounting their basis for the DSA model, the question may be asked, What is new and how does it compare? There are several potential differences between the DSA model and the Endsley and Jones 2001 Team SA Model.

(1) First, the implication of describing SA as "an emergent system property" that is distributed across the system is that it essentially is viewed as sufficient as long as the needed SA is distributed somewhere in the system (with another team member, on a display, in a report). The Endsley and Jones 2001 Team SA Model, on the other hand, says it is not sufficient that information is out there somewhere if the person who needs it is not aware of it. This is a fundamental difference between the two models.

"It does not matter if the individual human agents do not know everything, provided that the system has the information" (Stanton et al., 2010, p. 34). They provide the example of a pilot who presets 4 speed bugs to show the required speed of the aircraft at different points along the approach. "Clearly, the pilots are no longer required to remember the speed settings of the aircraft and, if asked via SAGAT or any other means, they would be unable to report the settings" (p. 35). I believe this example is seriously flawed and is not supported by research. Pilots will tell you that they do indeed need to know their approximate speed and further are able to do so quite accurately via SAGAT (Endsley, 1989; Endsley, Farley et al., 1998). The fact that they have aids that assist them with determining their desired speed does not obviate this need.

To the larger point, Stanton et al. (2010) state that "the concern is that by focusing solely in the individual mind or solely on the environment, much is missed in the understanding of the distributed and dynamic nature of SA in socio-technical systems. Even Endsley and colleagues do not object to the idea that SA can be distributed amongst human agents, so why not technological agents?" (p. 37). I have no problem in recognizing that data reside throughout the system, in both human and technological artifacts, and that an interesting set of processes occurs in gathering and using that information. Studies of scan patterns and communications, for instance, have long examined just that. However, I do not call such data, residing in a report or a display or an electronic system, "situation awareness." Inanimate objects do not have "awareness" of the situation or of anything else. They are simply repositories from which human decision makers may gather information of various types, through various means at various times.

Salmon et al. confuse sources of SA (displays, computers, and other artifacts) with SA itself, stating that the SA is in the artifact. This would only hold true if the artifact were itself a cognizant and independent decision maker. Information that exists in the environment, but which the decision maker is not aware of is by definition not SA. In a study of SA errors, Jones and Endsley (1996) found that 30% of Level 1 SA errors were in cases where all the information was present in their displays, but the operator failed to detect it for one reason or another. (This was the single highest causal factor associated with SA errors.) The ability to dynamically gather and update mentally one's understanding of the world and the system one is operating, particularly in worlds where information overload is a primary challenge, is critical and fundamental to having good SA and being able to make accurate, timely decisions. Simply relegating parts of the problem to "external resources" that have to get sampled appropriately fails to create a model that accounts for this critical aspect of successful SA.

Although certainly one does need to know where to find information to be successful, that knowledge alone is not sufficient in dynamic systems. For example, I know exactly where my speedometer is, but if I fail to monitor it I will still get a ticket when the police officer stops me for speeding. When the flight crew of an L1011 failed to monitor their altitude due to attentional narrowing on a warning light, the critical loss of SA resulted in a fatal crash for all aboard (National Transportation Safety Board, 1984). Just knowing where the altimeter was located and that they could look at any time was clearly not sufficient.

Many failures of SA are described in Jones and Endsley (1996). In all of these cases, the problem was not that the individual did not know where to find the needed information amongst his fellow teammates or systems, it is that the information failed to be known by the person who needed it, resulting in a significant performance problem or accident. Challenges such as task-related distractions, overreliance on automation, vigilance failures, forgetting key information, and poorly presented information caused SA failures, as did the lack of good mental models for correctly interpreting and projecting based on data that were perceived. The problem and challenges that serve to prevent successful information sharing in teams (both collocated and distributed teams) need to be dealt with to provide effective SA in teams, which the DSA model fails to accomplish with this view point.

Even where automated systems are present that ostensibly have the responsibility for SA and decision making involving the tasks under their purview, operators still need to have high-level SA of the state of the automation and the systems under its control in order to know whether they need to intervene or not (Endsley, 1996; Endsley & Kiris, 1995; Sarter, 2008; Sarter & Woods, 1995; Wiener & Curry, 1980). Out-of-the-loop performance problems that leave operators with poor SA, slow to detect and to diagnose automation problems and failures, have been highly documented as a critical performance problem in many systems (Endsley & Kaber, 1996; Kaber & Endsley, 1997b, 2004; Parasuraman & Riley, 1997; Wiener & Curry, 1980; Young, 1969). A model that holds that some of the SA is in the automation fails to account for the very real SA needs of the operators and the difficulties in obtaining it in modern systems. With most automated systems, the individual operator must have sufficient SA to oversee and intervene when needed.

Although one could postulate that one day we may have computer systems that are intelligent enough to have “situation models” analogous to human SA, as long as a human being has the requirement to have overall responsibility for the performance of the system, he or she will need to have the SA required to insure that the computer models are performing correctly. When a human no longer has that responsibility, then human SA will be moot and the automatons can take over. But I do not think this will be happening any time in the near future in most complex and safety-critical systems.

Despite an extensive discussion focused on how they believe SA is distributed across the system, they also state that “viewing the system as a whole, it does not matter if humans or technology own this information, just that the right information is activated and passed to the right agent at the right time” (Stanton et al., 2010, p. 34). This statement then does agree with the Endsley 1995 Model. So what is really different then? In my view, the DSA model fails to provide information on the cognitive mechanisms (or team mechanism) that are important in assuring that the needed information does get to the person who needs it (making sure the appropriate agent has the information when he or she needs it).

(2) Second, the DSA model tries to differentiate the types of SA that may or may not be shared in the system. “Agents therefore have different SA for the same situation, but their SA can be overlapping, compatible and complementary and deficiencies in one agent’s SA can be compensated by another agent” (Salmon et al., 2008, p. 313). Although Salmon et al. claim this is as a unique aspect of the model, in fact the Endsley and Jones 2001 Team SA Model describes in detail the ways in which SA in teams needs to be shared and consistent for overlapping SA requirements, and the ways in which it can be different (complementary) on other SA requirements, and provide methods for making that determination (Bolstad, Riley et al., 2002; Endsley, Hansman, & Farley, 1998).

Salmon, Stanton, Walker, Jenkins, and Rafferty (2010) state that “merely presenting this information in the same manner (as advocated by the shared SA view) may enable team member SA acquisition at a basic level, but it is debatable whether it fully supports team SA acquisition. It is the contention of our DSA model that presenting it in a manner that supports different team member views goes further to support DSA across the collaborative system” (p. 77). They make much of the fact that people need the individual SA required for their jobs as well as shared SA, and that people will draw different projections and understandings from even the same Level 1 data, saying this is an important difference, yet this is exactly what the Endsley and Jones 2001 Team SA model also prescribe, and what was empirically demonstrated by Bolstad and Endsley (1999).

For example, Bolstad, Riley et al. (2002) show in detail the ways in which different team members have unique SA needs, some portion of which are in common, and the ways in which team members need to draw different Level 2 and 3 SA, from even the same basic data. The Team SA model also shows how people can be consistent and inconsistent on those shared SA requirements and the ways in which displays need to be tailored to support both individual and shared SA. “The analyses also indicate that a single display will not meet the needs of all the brigade officers and therefore such displays need to be tailored to each officer, yet provide a window into the relevant SA of other officers in the team” (Bolstad, Riley et al., 2002, p. 474). Salmon et al.’s (2010) statements that the DSA model is unique in this respect are inaccurate.

(3) Third, the DSA model emphasizes that transactions are needed for one agent to update his or her SA with other agents. “Transactions are used to explain the information exchange between two agents in a system, one agent requesting information and the other agent supplying information to meet that request” (Stanton, 2010, p. 3). This, however, is also not novel. The Endsley and Jones 2001Team SA Model details the many ways in which such transactions can be made, through team SA devices, team SA mechanisms, and effective team SA processes, and they and other authors provide detailed examples of such transactions (Chute & Wiener, 1996; Gorman, Cooke, Pederson, Connor, & DeJoode, 2005; McDermott, Luck, Allender, & Fisher, 2005). Although there is nothing

wrong with examining such interactions, they provide only a limited depiction of the processes involved. DSA also does not account for much of SA that occurs silently—viewing, listening, and perceiving within the workspace—without observable or explicit communications or interactions.

So many of the features that DSA claims are new, corrections for the failure of previous models of SA, do not appear to be unique at all. Further, the DSA model fails to deal with many factors relevant to SA in teams. It provides no description or mechanisms for how team members share relevant information in complex domains. How do they know who needs what information when and at what level to share that information? How do people derive higher level SA from the data they share, and how can this be improved across teams? How do they know when to get information from the various sources in which it resides? The DSA model does not provide insight on such processes used in teams.

How to insure that the right information does get to the right agent at the right time is not addressed. Describing the physical actions it takes to push the sequence of buttons to bring up the right displays (an example of a DSA analysis, Sorenson et al., 2010) does not address the fundamental challenges associated with multitasking across competing goals, recognizing the significance of a piece of data, combining information across multiple sources, or knowing which displays to access upon receipt of a new piece of information. It does not address the fundamental challenges of arriving at an understanding of the significance of a piece of data or the processes by which projections of the near future are made to enable proactive decision making.

In the DSA model, as long as the data are there somewhere, that is sufficient, no matter how they are displayed or presented. Yet some 60 years of research in the human factors field shows this not to be true. How information is presented is highly critical to its readability, understandability, and accessibility, thus affecting human perception, cognition, and performance. The authors do not deny this fact, yet the model itself also does not effectively account for its importance. By relegating external artifacts to "possessing part of the SA" such issues would become unimportant. In my opinion, the DSA model fails to provide guidance on making information presentation more effective for building individual or team SA.

The Endsley 1995 Model of SA, in contrast, provides a detailed model of the cognitive processes involved in SA that have led to some 50 design guidelines for improving information presentation in systems to support SA, including six directed specifically at improving SA in team operations based on the Endsley and Jones 2001 Team SA Model. Based on these models, detailed procedures for objectively measuring individual and shared SA in teams have been developed. In addition, others have provided extensive research designed to measure individual and team SA processes (Bolstad et al., 2007; Cannon-Bowers et al., 1993; Chute & Wiener, 1996; Cooke et al., 2003; Cuevas, Jones, & Mossey, 2011; Gorman et al., 2005; Jones & Endsley, 2002; Mosier & Chidester, 1991; Orasanu, 1990; Salas et al., 1995; Scielzo, Strater, Tinsley, Ungvarsky, & Endsley, 2009). This literature base provides a detailed and useful understanding of team SA and how to support it.

## CONCLUSION

Over the past 25 years, the construct of SA has moved from revolutionary newcomer to the mainstream. Numerous articles have been written on what it is and how it works cognitively, based primarily on research in ecologically valid settings with experts. The SA construct evolved in real-world environments where pilots struggled to keep up with the rapidly changing information provided by a myriad of sensors, displays, and new technologies and the complexity and challenges of the flight environment, and has spread to a wide variety of domains that struggle with many of the same challenges. Initial questions about SA have been largely laid to rest, and substantive research has been conducted in the intervening years. Recent attempts to provide new models of SA provide a number of misconceptions regarding the Endsley 1995 Model of SA. These inaccuracies have been addressed here. Although valid disagreements will continue to exist on how various individual and team SA processes may occur, I hope these can be addressed through objective research findings and an accurate understanding of where real differences in these models do and do not exist.

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