A Computational Model of Situational Awareness Instantiated in MIDAS[1]

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Situational awareness (SA) is a concept that, while growing in popularity in the human performance literature, has suffered from the lack of consensus on a precise definition. McMillian (1996) cites fifteen different definitions from recent literature. Each pilot and researcher may have different definitions of this concept. In addition, no model has yet met the requirements for an SA model set forth by Gawron, Endsley & Reising (1995). However, the concept has obvious face validity and is a potentially important integrating psychological concept for situational analysis as a whole. The present work to develops an initial model that is strictly defined computationally and interacts with perceptual and cognitive models in a sophisticated simulation system, MIDAS. A brief description of this system follows.

MIDAS

The Man-machine Integration Design and Analysis System, or MIDAS, combines graphical equipment prototyping, dynamic simulation, and human performance modeling with the aim to reduce design cycle time, support quantitative predictions of human-system effectiveness, and improve the design of crew stations and their associated operating procedures. MIDAS is comprised of models of the major components of human-systems integration; 1) the symbolic operator (or human) , and 2) the world. Figure 1 depicts the current set of models in MIDAS. The symbolic operator model consists of perception and cognitive processes such as working memory, scheduling, decision making, and long-term memory, as well as the human figure model. The world models include the cockpit, or workstation model, the environmental model. The cockpit model is a fully functional high-fidelity representation. Figure 2 displays the AH-64 Longbow cockpit used in this demonstration. The Multi-Function Displays (MFDs) shown are fully functional and animated. The environmental model consists of elements in the world with which the crew station interacts, for example, trees, other aircraft, and tanks. The human figure anthropometric model is Jack®, developed by the University of Pennsylvania. Jack® is a dynamic human figure model that can be scaled in various anthropometric dimensions. For a more detailed description of the current MIDAS design, and a description of a planned re-design see, Smith and Tyler (1997).

SA Definition

Although consistent with one or more of the definitions of SA (e.g., Endsley, 1988b, Hancock & Smith, 1995), the definition adopted here is operational and quantifiable in nature. Simply put, SA is defined as the portion of situational elements that are known relative to the situational elements that define the ideal state. This definition refers to the actual SA of the operator. The model makes a distinction among actual, perceived, and error SA. These concepts, their computations, and their role in the model are explained in detail below.

SA Model

The model is comprised of three key features: 1) situational elements, 2) context-sensitive nodes, and 3) a regulatory mechanism, which will be referred to as the SA manager. For each specific situation, a set of related nodes specify the ideal SA. Pew (1995) offers the definition of situation that is adopted here, “A situation is a set of environmental conditions and system states with which the participant is interacting that can be characterized uniquely by a set of information, knowledge, and response options.” When the unique set no longer defines the situation, the situation has changed, and the weightings on the nodes must change, or the set of nodes themselves may be changed. Each of the three key features is discussed below.

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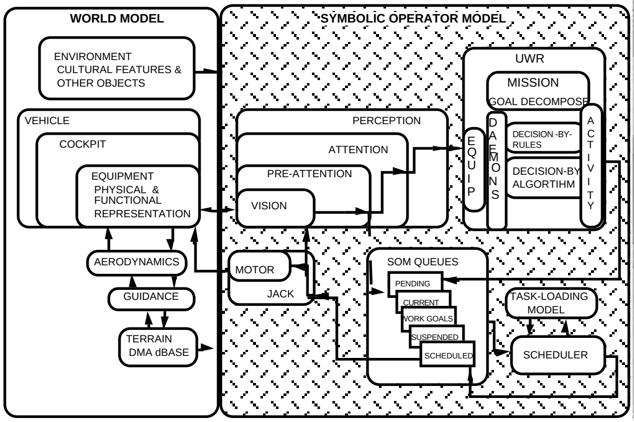

Figure 1. MIDAS architecture.

Figure 2. AH-64D Cockpit in MIDAS.

Situational Elements

The situational elements (SEs) are the components of the environment that define the situation. These include trees, tanks, hills, other aircraft, etc. Each SE is associated with a context-sensitive higher order node, if it is relevant to the situation. These are passed to the operator through perception, and are subject to the limitations of that process. Information concerning these SEs can also come from operator memory, based upon experience and expertise, or a pre-flight briefing. These SEs populate the nodes and to the extent that they fully populate the node, define the level of situational awareness. Not all SEs have the same level of importance in defining SA. Importance weights are therefore attached to each SE for a particular context. Each situational element has four increasing levels of awareness as shown in Table 1. A percentage was assigned to each category which represents the portion of total SA of that element contained within each level. The percentages are based on a logical progression of increasing information, the actual values have yet to be validated empirically.

Level	Characteristic	% SA
detection	Yes/No	20
recognition	category	50
identification	specific type	75
comprehension	contextual meaning	100

Table 1. Levels of Situational Awareness

Context-Sensitive Nodes

These nodes are semantically related collections of SEs (e.g., threats and targets). The nodes are defined by what is important in the situation. The nodes are weighted by the overall importance of the node in determining the level of SA. When the situation changes, the nodes must change to accurately reflect the ideal SA. The nodes reside in working memory and as such are subject to the limitations of that cognitive process, such as size limitations, temporal decay, etc.

SA manager

While the first two features of the model define SA, and are keys to its computation, the SA manager uses this information, and is the key to behavior regulation. The SA manager can be called by time, as in a pilot checking his/her SA every so often, or in response to changing conditions. The SA manager assesses the level of SA for each of the situational elements for all nodes with an importance weighting above a threshold as set by the MIDAS user. The manager flags those SEs that have a SA level below another threshold, again set by the analyst. It should be noted that the SA manager operates on perceived SA, with the error component intact (this distinction will be discussed in a later section). This is the only quantity available for the introspection of the pilot. An example should clarify how the model functions.

MIDAS tends to focus on intense analysis of a short section of a scenario called a snippet. This snippet begins with a digital message indicating preferred battle position, and continues through a reconnaissance bob-up, and missile firing. Table 2 shows the major tasks in the snippet.

Receive digital data transfer (DDT) and preferred fire zone
Acquire targets
Receive new DDT for target handover
Designate new targets
Engage first target - fire HELLFIRE missile
Engage second target - fire HELLFIRE missile
Engage two targets - Rapid fire two HELLFIRE missiles
Send battle damage assessment

Table 2. Co-pilot/gunner tasks in the MIDAS snippet.

AH-64A (Apache) helicopter pilots were interviewed to determine the important features that a pilot must be aware of in this particular context (an attack scenario). The importance weightings on these nodes change dramatically with phase of flight, or changing conditions (i.e., context-sensitive). In this situation the context-sensitive nodes and their weights are below. It is important to note that these are weightings for the co-pilot/gunner, hence the relatively low weight on own-aircraft.

1)	target/ threat	0.6
2)	battlefield	0.3
3)	own-aircraft	0.1

The target/threat node contains all those enemies that pose a threat to the own ship as well as those that are potential targets. The battlefield is a collection of those SEs that relate to the physical layout of the environment such as trees, hills, roads, etc. The last node is self-explanatory, it contains the controls and displays of the own-ship, as well as its relationship in space to the environment. Having defined the snippet and the nodes, the model must now know which SEs were passed to the operator, and at what level of awareness. Table 3 provides this information.

Element	Level	Proportion SA	Node
T-72(a)	Identification	0.75	threats/targets
T-72(b)	Unknown	0.0	threats/targets
Bulldozer/ZSU-23-4	*Comprehension/Err*	*1.00*	*threats/targets*
Junction	Comprehension	1.00	battlefield
Grove	Recognition	0.50	battlefield
Oak Trees	Comprehension	1.00	battlefield
Pine Trees	Identification	0.75	battlefield
Terrain	Detection	0.20	battlefield
Radar	Identification	0.75	own-ship
Altimeter	Comprehension	1.00	own-ship

Table 3. Level of awareness for each of the situational elements. Errors are indicated by italics.

SA Computation

Prior to computation of SA, a few definitions are in order. Ideal SA is defined as the actual state of the simulated situation. Pew (1995) distinguished between ideal and obtainable ideal. The obtainable ideal is that subset which is actually available for the crew member to acquire. Here, ideal SA corresponds to the obtainable ideal. Perceived SA is the level of SA that the pilot thinks he/she has, and potentially includes errors in perception/ identification, but does not include unknown elements. Error SA is a computation of the situational elements that are erroneously perceived or interpreted for some reason. Actual SA is differentiated from perceived SA by including the unknown elements and subtracting the error component. The computation should clarify these concepts.

Perceived SA

This variable is computed by taking a weighted average of the SA level for each known element in a node, and then multiplying it by the context-sensitive weight for that node. Total perceived SA is the summation across all nodes. For simplicity, we will use equal weightings for each of the SA elements. Equation 1 computes this value for the current example.

Perceived SA = [((0.75 + 1.0) / 2) * 0.6] + [((1.0 + 0.5 + 1.0 + 0.75 + 0.2) / 5) * 0.3] + [((.75 + 1.0) / 2) * .1] (1)
= 0.53 + 0.21 + 0.09
= 0.83

Error SA

An important aspect of SA that needs explicit definition is Error SA. As Will Rogers commented, " It's not the things that we don't know that get us into trouble; it's the things that we do know that ain't so." Error SA is computed in a similar fashion for those elements that are in error, either from perception, interpretation, or any other source. Here there is just one such element, the element identified as a ZSU-23-4 tracked anti-aircraft gun is actually a bulldozer. The denominator is now three, the total number of SEs as shown in Equation 2.

Error SA = (1.0 / 3) * 0.6 = 0.2 (2)

This indicates that of the total perceived SA = 0.84, of which 0.2 is in error. The ideal SA is set at 1.0, and it includes those elements that are unknown to the pilot. These values are computed at every cycle within MIDAS, at the rate of 100 msec, and are displayed as an output variable for MIDAS.

Actual SA

The actual SA, as noted earlier, includes the unknown elements, with a zero level of SA, and less the error component. In this example there is one unknown element in the threat/target node. The computation is shown in equation 3.

Actual SA = [((0.75 + 1.0 + 0.0) / 3) * 0.6] + [((1.0 + 0.5 + 1.0 + 0.75 + 0.2) / 5) * 0.3] + [((0.75 + 1.0) / 2) * 0.1] (3)
= 0.35 + 0.21 + 0.09
= (0.65) - error (0.2)
= 0.45

This represents the actual SA of the pilot in this situation.

Behavioral Regulation (SA manager)

The above example demonstrates the quantification of SA. This model also includes a regulatory mechanism. As stated earlier, two thresholds must be set by the MIDAS user (or accept default values). For this example, we will set node importance at 0.25, above which the node falls into the domain of the SA manager. That includes both the threat/ target node and the battlefield node. In addition, the acceptable level of SA for each SE needs to be defined. In this example, it is the recognition level. In our example, only one element falls below that level in a key node. That is the terrain SE in the battlefield node. The SA manager then seeks to raise the level of that element to an acceptable level. This is done by sending a task, such as a sensor scan, to the MIDAS scheduler. In this example, the scan raises the level of SA of the terrain element to comprehension, and it also comprehends a T-72 which was masked behind the terrain, T-72(b). The subsequent change in the SA computation is shown in equation 4.

Perceived SA = [((0.75 + 1.0 + 1.0) / 3) * 0.6] + [((1.0 + 0.5 + 1.0 + 0.75 + 1.0) / 5) * 0.3] (4)

+ [((0.75 + 1.0) / 2) * 0.1]
= 0.55 + 0.26 + 0.09
= 0.90

The error SA computation remains unchanged at 0.1.

There are now no unknown elements, so the calculation of actual SA is simply the perceived SA minus the error component, as shown in equation 5.

Actual SA = Perceived SA (0.90) - Error SA (0.10) (5)
= 0.80

Situation Changes

If as described in the introduction, the situation changes, then context-sensitive nodes must change. For example, the pilot might suddenly heard a loud noise, and experiences a hard right yaw. The immediate concern of the pilot is to determine what is has occurred, what the current aircraft status is, and the location of potential landing areas. Therefore the node weights may change to the ones shown below.

	Node	Weight
1)	Own-aircraft	0.9
2)	Landing areas	0.1

The SA manager will assess the overall level of SA, and determine the level of SA for the elements in the own-aircraft node. It will then send a task to the MIDAS scheduler to gather information on the own-aircraft situational elements.

MIDAS Output

The SA values computed are plotted against time as are other output variables for MIDAS simulations, as shown in Figure 3. This may highlight potential areas of concern to analysts and designers.

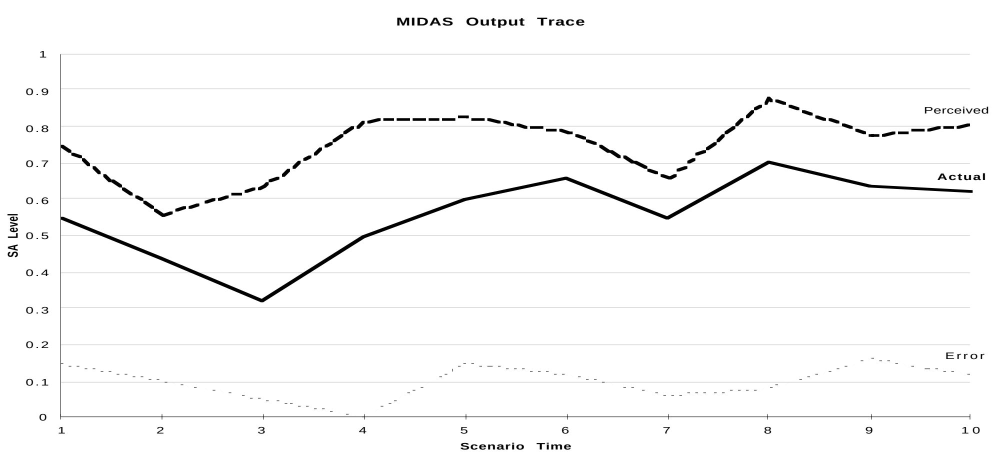

Figure 3. MIDAS SA Output

Caveats and Simplifying Assumptions

To progress to this point, several simplifying assumptions need to be made. This is not to indicate a lack of importance of these components of SA, only a realization that a first iteration of the model needed to be completed as a first step. One key issue in SA is an operator's confidence in the perception his/her SA. Many factors can affect this from experience, to performance feedback. We elected not to address this issue at this time, and to assume that the pilots had perfect confidence in their perception of SA. A second key feature of some SA definitions that we have elected not to address here is projection. However, it may be argued that if key situational elements have dynamic attributes, then they will be incorporated in defining the level of awareness for that element. However, this issue was not specifically addressed here.

Validation efforts

This is the initial effort in a three year program to develop and test a model of SA. The first phase of implementing the model in MIDAS is complete and will now undergo testing and iteration over the next 18 months. Initial testing will be at an analytical level. Variables that are known to affect situational awareness (e.g., visibility, initial information) will be manipulated to determine if the functioning of the model is in the predicted direction. Following this initial testing, and inevitable model revision, empirical testing will be undertaken. Similar scenarios will be evaluated in manned simulation and in the MIDAS-SA model. A battery of measures will be employed in the “man-in-the-loop” simulation, ranging from subjective, to performance-based, to retrospective. These data will be compared to the SA predictions of the model, not only for total SA, but also for the SA of the individual nodes. Early empirical efforts will utilize low-mid fidelity simulation, and later evaluations will move to high fidelity simulation in the Ames Research Center’s Vertical Motion Simulator. Evaluations may eventually be performed in flight research vehicles at Ames. This validation effort is consistent with the model-referenced performance measurement discussed by Pew (1995).

Applications

Efforts are currently underway to adapt this model for prediction of SA in other environments. The focus of those efforts, coordinated with NASA’s Advanced Air Traffic Technology (AATT) program, have been on the next generation air traffic management system, both for commercial air carrier pilots, and for rotorcraft pilots.

Summary and Implications

A quantifiable, testable model of situational awareness has been defined and implemented in an existing cognitive simulation. This model makes explicit the difference among actual, perceived, and error components of SA. Obviously, many assumptions needed to be made to allow us to get to this point, and inevitably many of those assumptions will prove to be in error. It is hoped that the research community will address these issues, and that this will lead to an improved understanding of situational awareness and its relationship to other perceptual and cognitive processes.

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