Summary of the various definitions of Situation Awareness

Beringer, D. B., and Hancock, P. A. (1989). Exploring situational awareness: A review and the effects of stress on rectilinear normalisation. In *Proceedings of the Fifth International Symposium on Aviation Psychology* (Volume 2, pp. 646-651). Columbus: Ohio State University.

The authors define SA in human/machine systems as conscious awareness of actions within two mutually embedded four-dimensional envelopes. The inner envelope is the unaided sensory space of the human operator, the outer envelope being information contained within the region of time and space presented to the operator via remote sensing. The envelopes are mutually embedded in that the unaided sensory space is physically part of the larger envelope, while the aided sensory space can convey information only via displays inside the smaller sensory envelope.

…

Billings, C. E. (1995). Situation awareness measurement and analysis: A commentary. *Proceedings of the International Conference on Experimental Analysis and Measurement of Situation Awareness,* Embry-Riddle Aeronautical University Press, FL.

SA is "an abstraction that exists within *our* minds, describing phenomena that we observe in humans performing work in a rich and usually dynamic environment."

…

Carol, L. A. (1992). Desperately seeking SA. *TAC Attack (TAC SP 127-1),* 32(3), 5-6.

SA is a pilot's (or aircrew's) continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission, and the ability to forecast, then execute tasks based on that perception.

It is problem solving in a three-dimensional spatial relationship complicated by the fourth dimension of time compression, where there are too few givens and too many variables. It encompasses the individual's experience and capabilities, which affect the ability to forecast, decide and then execute. SA represents the cumulative effects of everything an individual is and does as applied to mission accomplishment.

…

Dalrymple, M. A., and Schiflett. S. G. (1997). Measuring situational awareness of AWACS weapons directors. *Situational Awareness in the Tactical Air Environment: Augmented Proceedings of the Naval Air Warfare Center's First Annual Symposium, CSERIAC SOAR Report# 97-01*, WP-AFB: Ohio.

SA means that a human appropriately responds to important informational cues. This definition contains four key elements: (1) humans, (2) important informational cues, (3) behavioural cues, and (4) appropriateness of the responses. Important informational cues refer to environmental stimuli that are mentally processed by the human. The appropriateness of the responses implies the comparison of the response with an expected response or a number of possible expected responses. Expected responses form the basis for a performance measure of SA. Emerson, T. J., Reising, J. M., and Britten-Austin, H. G. (1987). Workload and situation awareness in future aircraft. *SAE Technical Paper* (No. 871803). Warrendale, PA: Society of Automotive Engineers.

Situation awareness can be defined as the crew's knowledge of both the internal and external states of the aircraft, as well as the environment in which it is operating.

The internal state of the aircraft refers to the 'health' of its utility systems, which must be monitored. The external environment refers to terrain, threats, and weather.

…

Endsley, M. R. (1988). *Situation awareness global assessment technique (SAGAT).* Paper presented at the National Aerospace and Electronic Conference (NAECON), Dayton, OH.

SA is "the pilot's internal model of the world around him at any point in time." It is derived from the aircraft instrumentation, the out-the-window view, and his or her senses. Individual capabilities, training, experience, objectives, and the ability to respond to task workload moderate the quality of the operator's SA.

…

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors, 37,* 65-84.

SA provides "the primary basis for subsequent decision making and performance in the operation of complex, dynamic systems..." At its lowest level the operator needs to perceive relevant information (in the environment, system, self, etc.), next integrate the data in conjunction with task goals, and, at its highest level, predict future events and system states based on this understanding.

…

Flach, J. M. (1995). Situation awareness: Proceed with caution. *Human Factors, 37,* 149-157.

"Clearly, SA is an appropriately descriptive label for a real and important behavioral phenomenon. The danger comes when researchers slip into thinking of SA as an objective cause of anything. A statement that SA or loss of SA is the leading cause of human error in military aviation mishaps might be criticised as circular reasoning: How does one know that SA was lost? Because the human responded inappropriately? Why did the human respond inappropriately? Because SA was lost. Is this keen insight or muddled thinking?"

…

Green, M., Odom, J. V., and Yates, J. T. (1995). Measuring situational awareness with the "Ideal Observer". *Proceedings of the International Conference on Experimental Analysis and Measurement of Situation Awareness,* Embry-Riddle Aeronautical University Press, FL.

SA requires an operator to "quickly detect, integrate and interpret data gathered from the environment. In many real-world conditions, situational awareness is hampered by two factors. First, the data may be spread throughout the visual field... Second, the data are frequently noisy."

…

Haines, R. F., and Flateau, C. (1992). *Night Flying.* Blue Ridge Summit, PA: TAB Books.

One's ability to remain aware of everything that is happening at the same time and to integrate that sense of awareness into what one is doing at the moment.

…

Hamilton, W. L. (1987). *Situation Awareness Metrics Program* (SAE Technical Paper Series No. 871767).
Warrendale, PA: Society of Automotive Engineers.

Situation awareness is knowledge of current and near-term disposition of both friendly and enemy forces within a volume of airspace.

…

Hartman, B. O., and Secrist, G. E. (1991). Situational awareness is more than exceptional vision. *Aviation,*
Space, and Environmental Medicine, 62, 1084-1089.

Situational awareness is principally (though not exclusively) cognitive, enriched by experience.

…

Harwood, K., Barnett, B., and Wickens, C. (1988). Situational awareness: A conceptual and methodological framework. In *Proceedings of the Psychology in the Department of Defense Eleventh Symposium* (Tech. Report No. USAFA-TR-88-1, pp. 316-320). Colorado Springs, CO: US Air Force Academy (AD-A198723).

The authors distil four SA dimensions from a collection of definitions: where, what, when, and who. Where refers to spatial awareness, what characterises identity awareness, who is associated with responsibility or automation awareness, and when signifies temporal awareness.

…

McMillan, G. R. (1994). Report of the Armstrong Laboratory Situation Awareness Integration (SAINT) Team (Briefing Transcript). In *Situation Awareness: Papers and Annotated Bibliography (U).* Armstrong Laboratory, Wright-Patterson AFB: OH.

A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission, and the ability to forecast, then execute tasks based on that perception.

…

Oliver, J. G. (1990). *Improving situational awareness through use of intuitive pictorial displays* (SAE Technical Paper Series, No. 901829). Warrendale, PA: SAE.

"The Aerospace Glossary for Human Factors Engineers defines situational awareness as, keeping track of the prioritised significant events and conditions in one's environment."

…

Regal, D. M., Rogers, W. H., and Boucek, G. P. (1988). Situational awareness in the commercial flight deck – definition, measurement, and enhancement. In *Proceedings of the 7th SAE Aerospace Behavioral Technology Conference* (65-69).

"Situational awareness can be defined at a number of different levels. At a higher level, we might say that it simply means that the pilot has an integrated understanding of factors that will contribute to the safe flying of the aircraft under normal or non-normal conditions. The broader this knowledge is, the greater the degree of situational awareness. As situational awareness increases, it is thought that the pilot is increasingly able to ‘think ahead of the aircraft,’ and that he can do this for a wider variety of situations.”

…

Sarter, N. B. and Woods, D. D. (1991). Situation Awareness: A critical but ill-defined phenomenon. *International Journal of Aviation Psychology, 1*, 45-57.

Definitions of SA typically attempt to specify the components or contents of SA, and/or make mention of the temporal dimension involved. The components of SA are, however, context dependent, and the temporal dimension largely operator dependent. Any attempt, therefore, to incorporate the context-sensitivity and temporal nature of SA into a definition runs the risk of being overly general.

“Situation awareness is based on the integration of knowledge resulting from recurrent situation assessments.”

…

Smith, K., and Hancock, P. A. (1995). The risk space representation of commercial airspace. In *Proceedings of the 8th International Symposium on Aviation Psychology*, Columbus: OH.

“Situation awareness is adaptive, externally-directed consciousness that has as its products knowledge about a dynamic task environment and directed action within that environment.”

SA, as we define it, is a specific brand of adaptation. Adaptation is the process by which an agent channels its knowledge and behaviour to attain goals, tempered by the conditions and constraints imposed by the task environment… a dynamic concept that exists at the interface between the agent and its environment.

…

Taylor, R. M. (1990). Situation awareness rating technique (SART): the development of a tool for aircrew systems design. In *Situational Awareness in Aerospace Operations* (Chapter 3). France: Neuilly-sur-Seine, NATO-AGARD-CP-478.

Situational awareness is probably the pre-requisite state of knowledge for making adaptive decisions in situations involving uncertainty, i.e. a veridical model of reality.

Situational awareness is the knowledge, cognition and anticipation of events, factors and variables affecting the safe, expedient and effective conduct of the mission.

…

Tenney, Y. J., Adams, M. J., Pew, R. W., Huggins, A. W., and Rogers, W. H. (1992). *A principled approach to the measurement of situation awareness in commercial aviation*. NASA contractor report 4451, Langley Research Center: NASA.

Although “situation awareness contributes to good performance, it is not synonymous with it. It is possible to have good SA and still not be a good pilot because of poor motor skills, co-ordination or attitude problems. Conversely, under automated flight conditions it is possible to have good performance with minimal SA.”

…

Vidulich, M. (1994). Cognitive and performance components of situation awareness: SAINT team task one
port. In *Situation Awareness: Papers and Annotated Bibliography (U).* Armstrong Laboratory, Wright-Patterson AFB: OH.

"In psychological terms, this means (that) SA involves more than perception or pattern recognition: it doubtless requires use of all the higher cognitive functions a person can bring to a task."

…

Vidulich, M. A. (1995). The role of scope as a feature of situation awareness metrics. *Proceedings of the International Conference on Experimental Analysis and Measurement of Situation Awareness,* Embry-Riddle Aeronautical University Press, FL.

Situation awareness (SA) refers to the pilot's cognitive understanding of the current situation and its implications.

…

Wickens, C. D. (1992). Workload and situation awareness: An analogy of history and implications. *Insight:*
The Visual Performance Technical group Newsletter, 14(4), 1-3.

"Situation Awareness refers to the ability to rapidly bring to consciousness those characteristics that *evolve* during a flight."

"Notice that the 'evolve' part of this definition excludes other information, like declarative and procedural knowledge, that may be rapidly brought to mind. Notice too that 'the ability to bring' allows SA to refer to things that may not *at that moment* be in consciousness (or working memory, if you choose). But you have to be able to grab them when you need them."

1 Situation Awareness and Crisis Management

1.1 Situation Awareness

By the late 1980s, there was a growing interest in understanding how pilots maintain awareness of the many complex and dynamic events that occur simultaneously in flight, and how this information was used to guide future actions. This increased interest was predominantly due to the vast quantities of sensor information available in the modern cockpit, coupled with the flightcrew's 'new' role as a monitor of aircraft automation. The term 'situation(al) awareness' (SA) was adopted to describe the processes of attention, perception, and decision making that together form a pilot's mental model of the current situation (Endsley, 1995; Adams, Tenney, and Pew, 1995). Today, SA is one of the most prominent research topics in the aviation Human Factors field.

Using this construct as a starting point, the aviation psychology community sought to revisit the classic issues of pilot selection, pilot training and flightdeck interface design. Concerning pilot selection and training, SA researchers asked 'Why are some pilots successful while others are not?' Is it some innate trait that certain crews have, or are there certain definable information processing skills that can be learned by any pilot given the appropriate training? Concerning cockpit interface design, researchers have attempted to develop design principles that facilitate SA, with the emphasis on providing increasingly more information to the pilot without overloading the pilot's cognitive and visual-perceptual system.

Whilst the majority of people will agree that the applications of SA research are clearly significant, there has been much debate concerning the measurement of SA and the resultant operational value of the construct (Flach, 1995; Goettl, 1997; Andre and Hancock, 1995). Moreover, it has been argued that the vast body of SA literature that has been generated has had a minimal impact on operational selection, training or design activities (Flach, 1995). It is within this context that a comprehensive review of the SA literature will be presented.

To date SA researchers have focused primarily on measuring a pilot's knowledge or awareness at a given point in time[1], with little consideration for how that information was obtained or the resource or workload constraints on processing that information. Clearly, in order to predict SA, or to understand how a given pilot's SA was formed, it is necessary to develop computational models and test batteries that consider the information acquisition behaviours of the pilots and the resources available for processing that information into decisions and actions. It should therefore be emphasised that future SA research must address *how* crew obtain SA, and under what resource and workload *conditions* they can best obtain and utilise their SA – rather than focusing merely on *how much* SA they have at any given moment in time. This is clearly a mammoth task for any researcher to undertake; however, an attempt will be made in this review to list the multitude of factors impacting on SA.

1.1.1 Definitions of Situation Awareness

1.1.1.1 Introduction/overview

Defining SA is no simple task because the term means many things to many people. Of course, any definition general enough to account for anything and everything related to piloting (or controlling) might prove too broad to be useful. On the other hand, overly specific definitions often prevent us from transferring concepts, issues, and results from one domain to another.

Below is a discussion of the various definitions of SA. Andre (1998) identified and extracted the pertinent and useful SA definitions from vast quantities of literature in the Human Factors domain.

1.1.1.2 Product versus process definitions

In recent years, an increasing number of researchers have distinguished between SA as a **product** and SA as a **process**. The vast majority of SA research has concentrated on measuring the '*product of SA*', i.e. measures of SA in a particular context, at a particular point in time. Indeed, many of the SA measures that will be outlined later in this review fall under the rubric of '*product measures*'. Andre (1998) argues that 'product research' has avoided the issue of how the information was obtained or the resource or workload constraints on processing that information. Clearly, in order to predict SA or to understand how a given pilot's SA was formed it is necessary to consider the information acquisition behaviours and the resources available for processing that information into decisions and actions.

It should therefore be emphasised that future SA research must address *how* crew obtain SA, and under what resource and workload *conditions* they can best obtain and utilise their SA – rather than focusing merely on *how much* SA they have at any given moment in time. This issue is particularly salient for the ESSAI project, which aims to identify methods for training SA – one cannot train SA if the question of *how* crews obtain SA has been ignored.

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[1] The majority of the early SA literature was aimed at military cockpits.

The following definitions of SA can be regarded as acknowledging the distinction between SA as a product and a process. Additionally, Andre (1998) and Banbury, Andre and Croft (in press) propose their own synthesised definition of SA that clearly demarcates the differences between product and process. For this definition, they distinguish between *'situation knowledge'*, *'Situation Awareness'* and *'situation assessment'*. . . .

The authors define crew SA as – 'their moment by moment ability to monitor and understand the state of the aircraft, its systems, and its environment. (It is a central theme of this paper that) achieving SA requires active attentional and inferential processes and involves significant perceptual and cognitive resources. As such, acquiring and maintaining situational awareness must be appreciated as an integral part of the crew's mental workload. We distinguish the process of achieving SA from its product; if we wish to measure and improve the product, we must understand the mental dynamics and constraints through which it is achieved.' (p. 519)

. . .

Dominguez, C. (1994). Can SA be defined? In *Situation Awareness: Papers and Annotated Bibliography (U).* Armstrong Laboratory, Wright-Patterson AFB: OH.

In terms of aviation processes and products, 'the process of SA refers to ***how*** SA is developed and maintained during flight, while the product is the resultant, elusive ***thing*** we call SA itself.'

Based on this author's review of the literature on SA the following definition was proposed in an attempt to unify the construct:

> 'Continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events.'

. . .

Banbury, S.P., Andre, A.D., and Croft, D.G. (in press). Do we 'know' all that we 'know'? The role of implicit knowledge in Situation Awareness. *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting.* San Diego, CA: HFES.

Andre, A. D. (1998). Measures of Situation Awareness: A critical review. *Technical report prepared for the Defence Evaluation and Research Agency*.

Situation Knowledge:

> "We use the term Situation Knowledge (SN) to refer to the total product of a pilot's capabilities, experience, goal-driven behaviours, information environment and resource constraints, and define SN as the pilot's dynamic, continuous internal assessment (or model) of the flight environment that drives his/her subsequent behaviours, predictions, decisions and responses."

What SN is**:**

- A pilot's *useful* (but not necessarily conscious) moment-to-moment knowledge about and understanding of the flight environment.
- Both implicit and explicit knowledge.
- Both declarative and procedural knowledge.

What SN is not:

- SN is not decision making, workload or performance. For example, it is possible to have high SN and poor performance (poor response execution), and to have low SN and good performance (e.g., automated flight). Thus while a pilot's SN drives the decisions and responses that constitute performance, many other factors (e.g., decision making biases, response slips) influence these same processes.

Situation Awareness:

> "We us the term Situation Awareness (SA) to refer to that portion of the product of an operator's capabilities, experience, goal-driven behaviours, information environment and resource constraints, that he/she can articulate."

What SA is:
- A pilot's *useful* moment-to-moment knowledge about, and understanding of, the flight environment.
- Only explicit, declarative knowledge.
- A subset of situation knowledge (SN).

What SA is not:
- SA is not decision making, workload or performance. For example, it is possible to have high SA and poor performance (poor response execution), and to have low SA and good performance (e.g., automated flight). Thus while a pilot's SA drives the decisions and responses that constitute performance, many other factors (e.g., decision making biases, response slips) influence these same processes.
- SA is not implicit knowledge.

Situation Assessment:

> "We use the term Situation Assessment (SAS) to refer to the active processes and behaviours (and conditions) that afford the development and maintenance of situation knowledge (SN). This includes all the processes an operator brings to bear on the development of SN – goals, perception, attention, dynamics, temporality, prediction, automaticity, motor skills, mapping, pattern recognition, training, motivation, experience, encoding skill, knowledge acquisition, retrieval, and storage."

What SAS is:
- The *process* of developing situation knowledge SN.
- The skills, behaviours and conditions that support acquisition of SN.

What SAS is not:
- Situation knowledge (SN) or Situation Awareness (SA).

1.1.1.3 Definition of Situation Awareness adopted for ESSAI

In developing a working definition of SA, it is important to realise that, much like other constructs (attention, workload, stress, risk, etc.), SA has no absolute, or 'correct' definition. Constructs are used by researchers and Human Factors practitioners to describe psychological theories or concepts that cannot be assessed or measured directly. The problem lies in the fact that anyone can choose to label their particular theory or concept as SA; a fact made abundantly clear by the large list of distinct definitions provided above.

The following SA definition has been agreed upon by the ESSAI consortium for use throughout this project:

> "…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future".
>
> Endsley, M.R. (1988). Design and evaluation for Situation Awareness enhancement. I*Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 97 – 101). Santa Monica, CA: Human Factors Society.

To expand upon this definition, Endsley, M.R., Farley, T.C., Jones, W.M., Midkiff, A.H. and Hansman, R.J. (1998) describe the three hierarchical phases of SA: perception, comprehension, and projection (also see Endsley's model in the next section of this review):

Level 1 SA **-**Perception of the elements in the environment

> "The first step in achieving SA involves perceiving the status, attributes, and dynamics of relevant elements in the environment. The pilot needs to accurately perceive information about his/her aircraft and its systems (airspeed, position, altitude, route, direction of flight, etc.), as well as weather, air traffic control clearances, emergency information, and other pertinent elements" (Endsley et al, 1998).

Level 2 SA **-**Comprehension of the current situation

> "Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present to include an understanding of the significance of those elements in light of the pilot's goals. Based upon knowledge of Level 1 elements, particularly when put together to form patterns with other elements, a holistic picture of the environment will be formed, including a comprehension of the significance of information and events" (Endsley et al, 1998).

Level 3 SA **-**Projection of future status

> "It is the ability to project the future actions of the elements in the environment, at least in the near term, that forms the third and highest level of Situation Awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA)" (Endsley et al, 1998).

The question remains how an individual acquires and maintains the appropriate level of SA. Dominguez (1994) argues that SA involves the extraction of information from the environment and the integration of this information with relevant internal knowledge to create a mental picture of the current situation. Of interest to this discussion is the statement that this picture is used to direct further exploration in a continual perceptual cycle, the result of which is used to anticipate future events. Thus, the essential concept within Dominguez's definition of SA is that the process of SA acquisition and maintenance is active and cyclical.

Clearly, the process of SA acquisition and maintenance is reliant on an active and cyclical process. However, the authors would like to posit that this process is also *adaptive*. For example, Neisser (1976) formulated the concept of a 'Perceptual Cycle', where the interaction between human and environment shapes the human's perceptions and actions. Neisser argued that the structure of our knowledge and expectations of some aspect of the world (i.e. schema) are always activated, but that the activation of particular schemata is as an oriented response to the environment. This oriented response selects new information for attention that in turn activates appropriate schemata and so on. Taylor et al. (1996) argues that Neisser's Perceptual Cycle presents a description of SA whereby human attention and awareness of the environment or situation are actively modified by the changing appreciation of information gleaned from that environment.

A similar model was proposed by Power's (1973: cited in Taylor et al., 1996) Perceptual Control Theory (PCT). This theory proposes that all behaviour be considered as concerned with the control of perception; actions are of value only if they affect favourably what can be perceived in relation to the intended goals. The role of feedback in goal directed behaviour is a fundamental element of PCT. In PCT, control is organised hierarchically into multiple layers, with higher-level 'meta-goals' such as self-esteem and conscientiousness, and lower-level goals such as survival. Action or behaviour is triggered in response to an error-correcting signal. This signal is communicated with the aim of changing the state of the world so that the operator's perception matches a desired state or goal. The fundamental claim of PCT is that it is the perception that is controlled and not the behaviour. Since behaviour is not the controlled factor, this model accounts for the wide individual differences that characterise the performance of real-world tasks.
Finnie and Taylor (1998) adapted Power's PCT to posit a model of SA (see figure 9). The main tenet of the IMPACT (Integrated Model of Perceived Awareness ConTrol) model being that SA, or the individual's perception of it, was controlled by behaviour. Similar to PCT, the acquisition and maintenance of SA is derived from behaviour directed to reduce the mis-match between the perceived level of SA and the desired level of SA.
Endsley's (1995) model of SA also utilises a feedback mechanism to direct behaviour in order to reach a desired level of SA. A reproduction of Endsley's (2000) model of SA is provided below (see Figure 10). However, Endsley makes it clear that a person's perception of the relevant elements in the environment forms the basis of SA. Actions and behaviour are treated as separate stages that proceed directly from SA. Indeed, Endsley states that SA is recognised as a construct separate from decision making and performance.

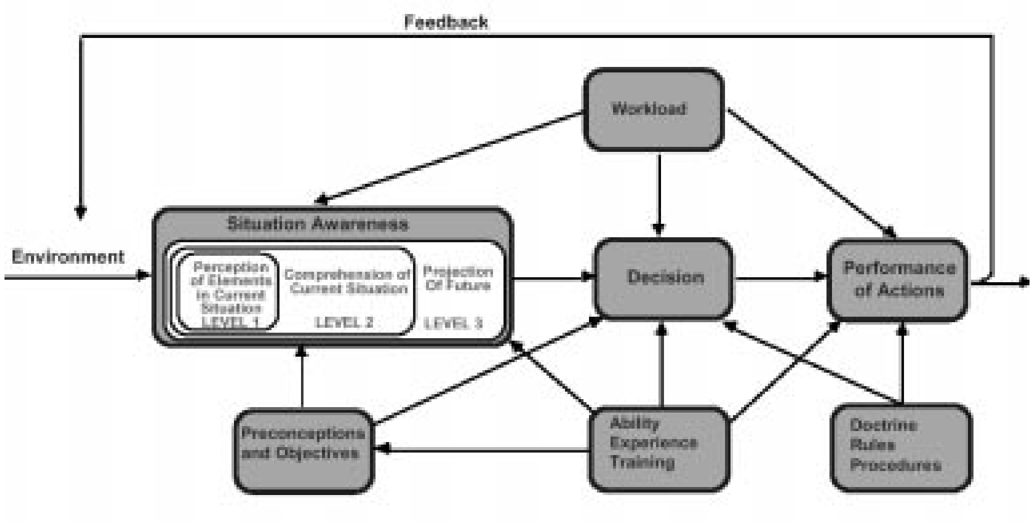

Figure 1: Endsley's Model of SA in dynamic decision making (adapted from Endsley, 2000)

Endsley (1995) states that there are a number of factors that have been shown to influence the process of acquiring and maintaining SA. First, individuals may vary in their ability to acquire SA as a function of their cognitive abilities, which in turn may be influenced by innate abilities, experience and training. In addition, individuals may possess certain preconceptions and objectives that can influence their perception and interpretation of their environment. Further, Endsley states that SA is also a function of the design of the system, both in terms of the degree to which the system provides the requisite information, and the format in which this information is provided. Finally, other features of the task environment, such as stress, workload, system complexity and so on, may also affect SA.

One can infer from Endsley's model that three important characteristics of SA are relevant to the current review:

- A differentiation between SA as a 'product' and SA as a 'process'.
- That the 'process' of acquiring and maintaining SA is cyclical and adaptive.
- That there are a number of factors both internal (i.e. self) and external (i.e. task environment) that affect the acquisition and maintenance of SA.