Sandom C, *Situational Awareness*, in Noyes J and Bransby M (Eds.), People in Control: Human Factors in Control Room Design, IEE Publishing, December 2001.

Chapter 4

Situation awareness

Carl Sandom

4.1 Introduction

This chapter will introduce a safety perspective into the development of systems which include people in control. Human systems are increasingly integrated into social contexts where their correct design and operation is essential in order to preserve the safety of the general public, the operators and the environment. However, many studies of human systems have in the past considered safety predominantly, or even exclusively, from a technical perspective. Unfortunately, these studies are typically limited to addressing the hazards arising through hardware failures alone despite the fact that human failures are more common in safety-related systems.

A consideration of the human factors during systems development often reveals a complex set of problems which are extremely challenging. The hazards associated with human failures are very different from the hazards which have historically been the concern of system designers since they arise directly from the *use* of the system and therefore require some understanding of the cognition and actions of users in context. The identification of interaction hazards arising during system use may help designers to improve the system interface such that the associated risks are mitigated or even eliminated. However, in order to study these interaction hazards, appropriate models and techniques are required to help systems developers.

Situation awareness is one phenomenon that can be profoundly affected by the design of human-computer interactions, particularly when a system is situated in a dynamic environment [Hopkin, 1995]. People in control of such systems must often pay attention to a large volume of information from a variety of sources including sensors and other operators in order to acquire an awareness of the situation in question. Situation awareness has therefore been the subject of much research in recent years, particularly within the field of aviation and other similarly complex domains [see for example Sandom, 2000; Harris, 1997; Garland and Endsley, 1995]. Studies such as these have shown that situation awareness should be a major safety consideration when developing interactive systems.

Situation awareness is a complex phenomenon without an accepted definition [Hopkin, 1995]. This chapter will examine the dominant perspectives of situation awareness and the major themes will be drawn from this examination to form a Situated Cognition perspective. From this perspective, a generic System Situation Awareness Model is introduced to represent both the human and technical factors which affect the Situation Awareness of people in control.

Finally, this chapter will introduce SAPAT (Situation Awareness Process Analysis Technique); a technique for applying the System Situation Awareness Model to the analysis of interactive control systems. The chapter will conclude with an explanation of how SAPAT can be used to identify those areas of an interactive system where safety should take precedence over usability.

4.2 Situation awareness – a perspective

Sarter and Woods [1991] identify Situation Awareness (SA) as a critical, but ill defined, phenomenon in complex, dynamic systems. SA has become a common phrase for both system designers and operators who often base its use on an intuitive understanding of its definition. Endsley [1995a] argued that a commonly accepted definition is a particular requirement for practitioners attempting to design and evaluate systems that rely upon operator awareness.

In the context of human-machine interaction, current definitions of SA are generally based on conflicting views of SA as either a cognitive phenomenon or as an observer construct; these can respectively be referred to as the Cognitive or Interactionist perspectives. The Cognitive perspective is the most prevalent view of SA as a cognitive phenomenon that occurs ‘in the head’ of an actor. In contrast, the relatively new Interactionist perspective regards SA as an abstract concept located ‘in the interaction’ between actor and environment. Despite the philosophical differences, a number of themes can be drawn from these perspectives to form the basis of a Situated Cognition perspective of situation awareness.

4.2.1 The Cognitive Perspective

Proponents of a cognitive perspective of SA view it as a phenomenon that occurs ‘in the head’ of an actor in a similar fashion to the dominant cognitive framework of the human as an information processor [Card *et al.,* 1983]. Indeed, some theorists even suggest that SA is yet another ‘black box’ component or sub-process within the human information-processing model [see for example Endsley, 1995b].

However, Cognitive perspective theorists often confusingly refer to SA as a cognitive process, a state of knowledge or both. With this distinction, *product* refers to the state of awareness with reference to knowledge and information, whereas *process* refers to the various cognitive activities involved in acquiring and maintaining SA. Sarter and Woods have proposed a typical process-oriented definition of SA:

> *“Situation awareness is the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments”* [Sarter and Woods, 1991, p.52].

Cognitive definitions of SA also generally provide a rich description of key elements of decision making activities in complex systems such as perception, comprehension and projection, as suggested by the definition of SA proposed by Endsley:

> *"Situation awareness is 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, 1995b, p.36].

Having implied the process-oriented nature of SA, however, Endsley [1995c, p.18] also confusingly states that, "SA can be described as a person's state of knowledge or mental model of the situation around them." To add to this confusion, Issac has also defined SA as both a product and process as in the following definition:

> *"SA refers to a cognitive state or process associated with the assessment of multiple cues in a dynamic situation. It may refer to a person's knowledge and reference to their status within a space and time continuum (pilot) or an operator prediction within a known space and time continuum (air traffic controller)"* [Issac 1997, p.185].

These different definitions of SA suggest an apparent lack of coherence within the Cognitive perspective of SA.

Nonetheless, Endsley's [1995b] theoretical model of SA, which is based on the role of SA in human decision making in dynamic systems, has been widely cited and highly influential in cognitive science research.

Endsley's SA Model [1995b] represents a typical cognitive perspective of SA and it proposes three different levels of SA which are relevant to this chapter:

- <u>Level 1 SA</u>. *Perception* of the status, attributes and dynamics of relevant elements in the environment.

- <u>Level 2 SA</u>. *Comprehension* of the situation based on a synthesis of disjointed Level 1 elements to form a holistic 'picture' of the environment.

- <u>Level 3 SA</u>. *Projection* of the near-term future of the elements in the environment.

Endsley's [1995b] model suggests that SA is based on more than simply perceiving information about the environment, which is often the intuitive definition of the phenomenon.

Many cognitive accounts of SA suggest that after information concerning relevant elements is perceived, a representation of the situation must be formed before a decision can be made based upon current SA. Kirwan *et al.* [1998] contend that Air Traffic Controllers have a mental representation of the air traffic situation which includes what has happened, what could happen and what they would like to happen based on their goals and objectives. Kirwan *et al.* [1998] also suggest that this mental representation (or model) can be visual, verbal or both. Mental models such as these may be regarded as a dynamic mental representations of a situation that allow operators to make predictions about future states and to make inferences regarding situations not experienced before.

Clearly, there are striking similarities between this general definition of a mental model and Endsley's [1995b] process-oriented definition of SA given previously.

4.2.2 The Interactionist Perspective

In contrast to the Cognitive school, there is a competing and developing view of SA which can be termed the Interactionist perspective. Interactionists share a common view of SA as an observed construct associated with the user's interaction with the system. From this perspective SA is regarded to be an abstraction that exists only in the mind of an observer. SA is thus considered as a useful description of a phenomenon that can be observed in humans performing work through interacting with complex and dynamic environments [Billings, 1995; Flach, 1995a]. The description is developed by considering observable behaviour in the environment – what the user does, how the system performs – but is not concerned with directly relating these things with cognitive states of the user.

In one sense this might be associated with traditional behavioural psychology. A behavioural stance may simplify the discussion of SA by removing (or at least marginalizing) interest in the user's mental state in favour of a reliance on observable action. A behaviourist stance is however much less rich as a research perspective, since no attempt will be made to relate action to intention on the user's part. In moving the SA debate forward, and looking for rich models to explain SA, identify hazards and ultimately inform the design of safety-related systems, it is suggested here that cognitive views of SA are necessary.

Yet, there are competing views of SA which do not fit neatly into the information-processing position predominantly taken by the cognitive school, but which might be useful in developing an informed stance on SA. Smith and Hancock [1995] for example, propose a view of SA as adaptive and externally directed consciousness, arguing that there is currently an artificial and contentious division evident within the literature relating to general perspectives of SA as either exclusively knowledge (i.e., cognitive state, or product) or exclusively process.

From the interactionist view, SA specifies *what must be known* to solve a class of problems posed when interacting with a dynamic environment. Smith and Hancock [1995] also criticise the lack of dynamism exhibited in the cognitive perspective, contending that SA is a dynamic concept that exists at the interface between a user and their environment. Moreover, they argue that SA is a generative process of knowledge creation and informed action taking as opposed to merely a snapshot of a user's mental model.

There are merits in many of the competing perspectives of SA, and the range of views that exists highlights the complexity and the general immaturity of research in this area. The mental state of the user is important in trying to understand the awareness that the user builds up of a situation. Yet often only observable interaction data is available, tempting researchers to marginalize the mental state as a concern and focus on explaining SA without reference to the user's cognitive processes.

4.2.3 A Situated Cognition Perspective

A synthetic, and perhaps pragmatic, perspective sees SA as a measure of the degree of dynamic coupling between a user and a particular situation [Flach, 1995b]. This view attaches importance both to the user's cognitive state and to the context or situation in which they are interacting. This reflects a move away from traditional information processing models of cognition characterised by the ubiquitous model human processor proposed by Card *et al*. [1983] towards a situated cognition (and situated action) perspective.

Proponents of the situated perspective generally agree that the information processing approach to HCI has neglected the importance of how people work when using computer systems situated in the context of the real world [see for example Nardi, 1996; Hutchins, 1995; Suchman, 1987; Winograd and Flores, 1986]. Landauer [1987, p.5] summed up this link between cognition and context aptly: “There is no sense in which we can study cognition meaningfully divorced from the tasks and contexts in which it finds itself in the world”.

A Situated Cognition perspective of SA addresses how the current awareness of a situation affects the process of acquiring and interpreting new awareness in an ongoing cycle. This view is similar to Neisser’s Perception-Action Cycle [Neisser, 1976] which has been used to model SA [see Adams *et al.*, 1995; Smith and Hancock, 1995] in an attempt to capture the dynamic nature of the phenomenon. Central to this view of SA is the contribution of active perception on the part of the user in making sense of the situation in which they are acting. Such active perception suggests informed, directed behaviour on the part of the user.

Neisser [1967] proposed a cognitive framework, which has been highly influential in cognitive psychology research into human behaviour in complex systems. His original framework partitioned the human information-processing system and subsequent research was directed at quantifying constraints, such as memory capacity, within each stage. Neisser [1976] subsequently expanded his model of cognition and he proposed the Perception-Action Cycle to reflect his assertion that *active perception* will unavoidably encounter unexpected situation elements or even fail to find them.

A tangible benefit of this perspective of SA is the focus on the inseparability of situations and awareness [Flach, 1995b]. Discussions of SA focus attention on both what is inside the head (awareness from a cognitive perspective) and also what the head is inside (the situation which provides observable data) [Mace, 1977]. Generally, this stance suggests that the user’s current awareness of a situation affects the process of acquiring and interpreting new awareness from the environment in an ongoing cycle.

4.3 A situation awareness process model

As the preceding discussions have highlighted, there are competing and sometimes confusing views on SA and its relation to people and the situation in which they are acting. Four important themes will now be drawn from the theoretical perspectives discussed and these themes will be used as a framework to develop a model for the evaluation of the SA process within the human component of a system.

4.3.1 Awareness

As the discussion of the competing perspectives highlighted, the term SA is often used to describe the experience of comprehending what is happening in a complex, dynamic environment in relation to an overall objective or goal. Regardless of theoretical perspective, it is generally accepted that this experience involves both acquiring and maintaining a state of awareness [Endsley, 1995b; Smith and Hancock, 1995]. This view is shared by Dominguez [1994] who, in an attempt to define SA as both a process and a product, compared 15 definitions and concluded that the perception of expected information in the environment occurs in a continual cycle which is described as *continuous extraction*. To be useful therefore, a perspective of

SA should reflect the equal importance of both the continuous process of acquiring and maintaining SA and the state of SA itself.

4.3.2 Situated Action

An area that is seen as important, but on which there is much academic disagreement, is consciousness. Compare, for example, the description of Endsley's [1995b] model of SA with that prescribed by Smith and Hancock [1995]. If research in SA is to take a broader perspective than that offered by the information-processing model, it will have to concern itself with issues which reflect deliberate action on the part of those being studied in the specific context in which they are acting. A perspective informed by this stance would have to acknowledge the existence of situated action [Suchman, 1987], and reflect that an operator's awareness of a situation consciously affects the process of acquiring and interpreting new information in a continuous, proactive cycle.

4.3.3 Context

The positions taken in paragraphs 4.3.1 and 4.3.2 reflect the importance of the operator making sense of situations in a particular context, and frame SA in this light. Any perspective of SA should explicitly reflect this, showing that accurate interpretations of a situation cannot be made without an understanding of the significance of the situation within a particular context. In other words, the context in which an operator is acting has to be understood in order to appreciate the importance of particular situations and their likely relation to SA. This coupling of situation to context is suggested as a key issue and, as discussed earlier, is one which has emerged as a theme of increasing importance in cognitive science and HCI.

4.3.4 Dynamism

When an operator is making sense of the situation in which they are acting, their understanding is informed by them extracting relevant information from their environment. This information is temporal; the same information at different times (and therefore in different situations) may mean different things to an operator. The continuous information extraction process in which the operator is engaged implies that SA requires operators to diagnose past problems and provide prognosis and prevention of future problems based on an understanding of current information. This suggests that a perspective of SA must be inherently dynamic, reflecting the development of SA over time, and that it must be responsive to environmental changes, for example in the information available to the operator.

As we have seen, SA is an ill-defined, but critical phenomenon for operators in complex, interactive systems. However, as discussed here, one of the problems in making use of SA is the conflicting theoretical perspectives from which SA has been described and researched. Whilst it is recognised that theoretical debate is both healthy and necessary, it is suggested here that a Situated Cognition perspective may be a more immediate way of contributing to system design. The four themes outlined above form the basis of what can be described as a Situated Cognition approach to SA based upon a synthesis of important concepts from a review of the different theoretical perspectives. These themes are therefore used here to frame a model of the SA process shown in Figure 4.1.

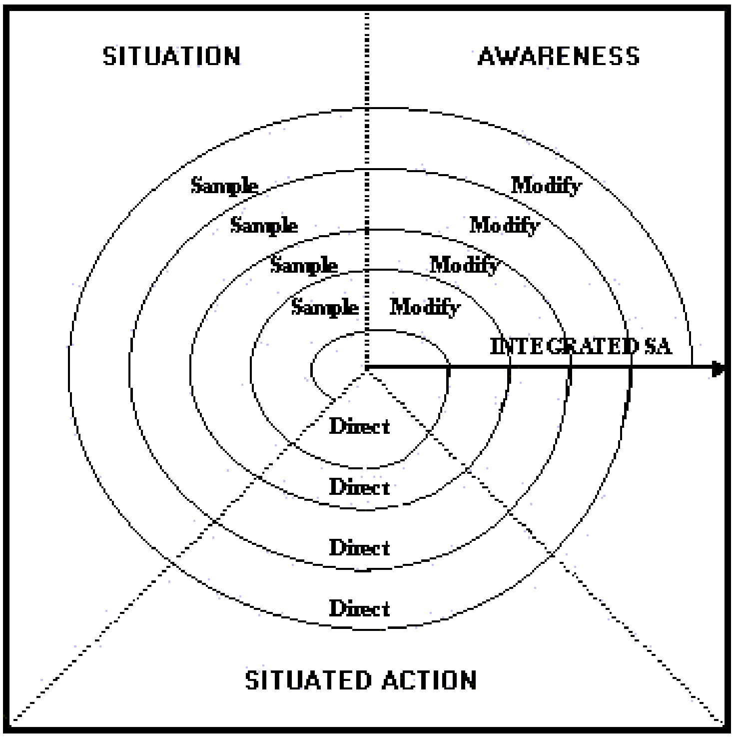

Figure 4.1 An SA Process Model [adapted from Neisser, 1976]

The SA Process Model in Figure 4.1 is adapted from Neisser's Perception-Action Cycle [1976] which focuses on the adaptive, interactive relationship between an actor and their environment. Pictorially, the SA Process Model owes much to Boehm's Spiral Model of the software development life-cycle [Boehm, 1988] which is also centrally concerned with issues of iteration and dynamism. It also shows that awareness information is continuously extracted from a real-world situation and that this is integrated into an operator's awareness to form a mental representation upon which decisions are based and exploratory actions are taken.

The SA Process Model shows the inseparability of the SA acquisition process and the resulting (product) state of awareness that recursively direct the selection of relevant situation information in a continuous cycle. It is worth noting that Norman's well cited action model [Norman, 1988] appears very similar to Neisser's Perception-Action Model. An important difference, however, is that Neisser maintains that knowledge (or awareness) leads to anticipation of certain information that directs the sampling strategy and increases an operator's receptivity to some elements of the available information.

In Figure 4.1, the three terms 'sample', 'modify' and 'direct' are used. In Neisser's model, these terms are related to the 'environment', 'knowledge' and 'action' respectively. In the adapted SA Process Model the terms relate directly to the areas of situation, awareness, and situated action. For the purpose of using Neisser's model in the context of SA, the terms 'situation' and 'awareness' are substituted for 'environment' and 'knowledge' to imply that only a subset of elements of the environment and knowledge relevant to a specific task are considered. This is consistent with the view of SA espoused by Endsley [1995b].

As the operator begins to interact in their environment, they can be considered as moving along the spiral in the model from the central point. An operator may start anywhere in the cycle as, for example, a routine may take over to provoke initial action. Starting arbitrarily, the operator will *sample* the situation, building a perception of it by extracting and interpreting information content. This may lead the operator to *modify* their awareness, developing their subjective mental representation of the situation in which they are interacting. Changes in the operator's interpretation of the situation cause them to consciously *direct* their action (including what/where to sample next), anticipating future states in which they might find themselves and acting accordingly. The 'sample–modify–direct' cycle which the operator can be thought of as having passed through will have developed their awareness in a particular way. As time progresses the operator will cycle through these phases building an integrated awareness that grows with each iteration.

4.4 A system situation awareness model

An SA Process Model was developed in the previous section to represent the SA acquisition process of the human operator *in-situ*. However, to carry out a true systems analysis, what we require is to model of the complete human and technical system in terms of SA. If we need to undertake an analysis of the hazards in an interactive control system we need to consider SA-related interactions from a controller's perspective. In particular, we need to identify those which are hazardous to enable us to mitigate the risks associated with these interactions.

It is therefore necessary to develop a model of a typical control system (based on its functionality) and the SA-related interactions that can affect the operator. Such an SA Interaction Model could then be integrated with the SA Process Model in Figure 4.1 (representing the human factor from an operator's perspective) to constitute a generic System SA Model. A model such as this is presented in Figure 4.2.

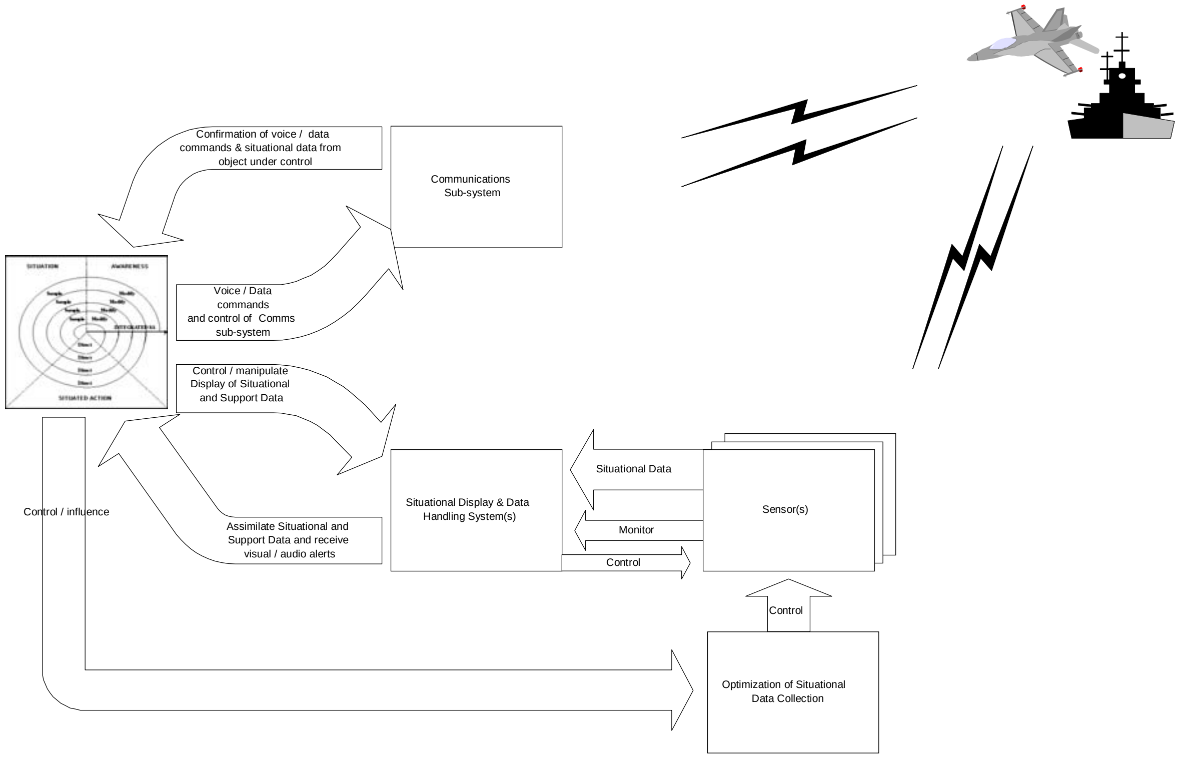

Figure 4.2 A System SA Model

The System SA Model in Figure 4.2 is a generic system model intended to represent a typical interactive system where people are in control of a process such as an Air Traffic Control system for example. These systems typically present situation data to an operator through a communications sub-system, a display and (possibly) a remote method of optimising the situation data collection sensors involving other system operators. For example, a railway control room operator will sample situation data from, radio and/or telephone communications, a large screen display and a computer console, and the signals can be manually adjusted by signallers co-located with the remote signal sensors to optimise the railway system. Clearly, the model can be adapted to represent the interaction of a specific control system.

Together with the System SA Model in Figure 4.2 we now have a model to represent both the human and technical factors within a system. This model can now be used to undertake an analysis of the hazardous interactions which can affect the SA of an operator in the context of a control system's environment. Moreover, the model represents *both* the human and technical factors which can affect SA and the people in control of safety.

4.5 SAPAT – SA Process Analysis Technique

Having described a model for the evaluation of SA, it is necessary to develop a method of applying the model to the analysis of interactive control systems and ultimately an evaluation of system safety. For theoretical coherence, a method that uses the System SA Model (and specifically the integrated SA Process Model) as a tool must also be consistent with the Situated Cognition perspective of SA discussed in Section 4.2.3.

SA Process Analysis Technique (SAPAT), shown in Figure 4.3, is a technique that can be used for the analysis of the SA process.

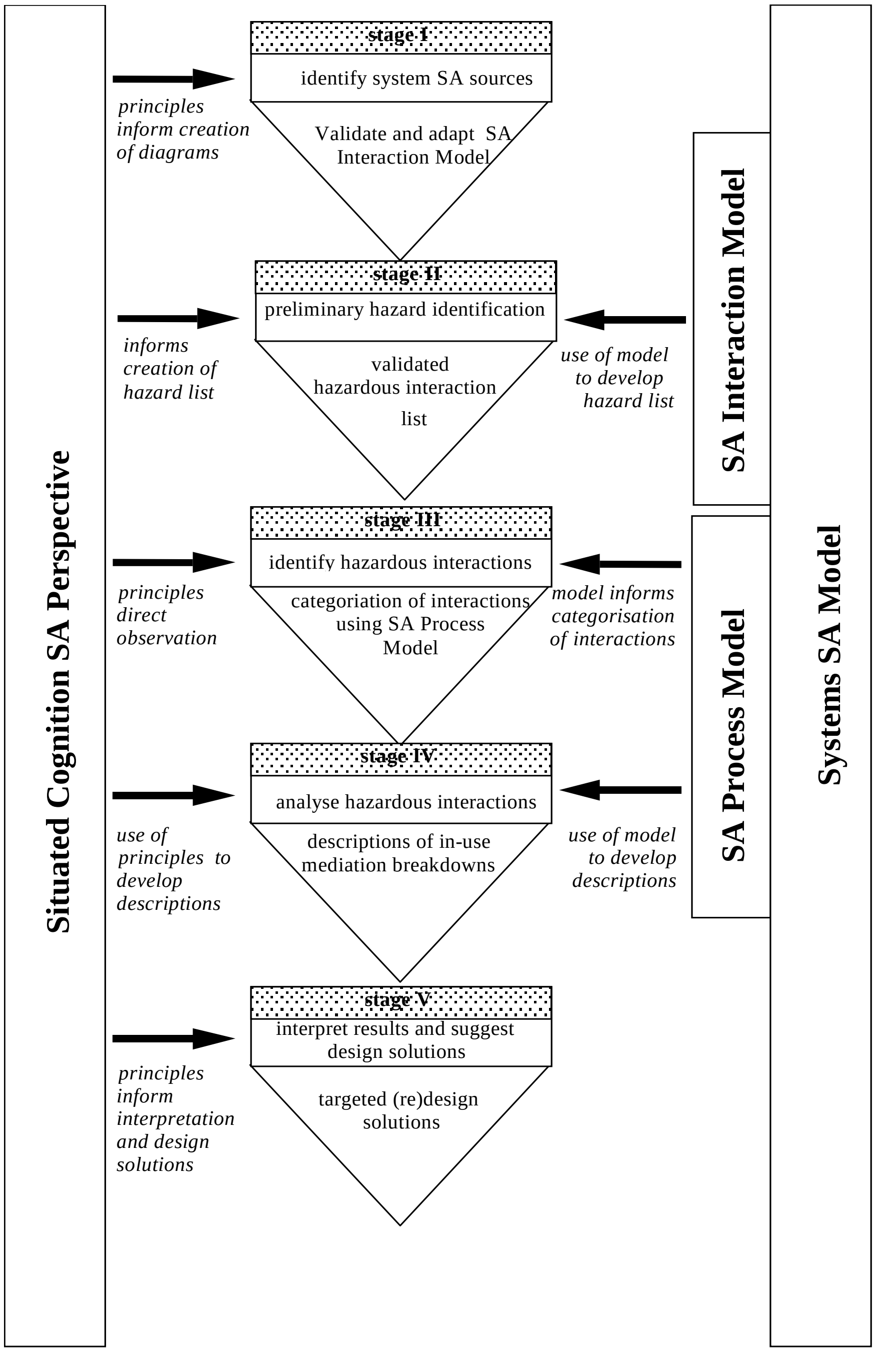

Figure 4.3 SA Process Analysis Technique [SAPAT]

The SAPAT diagram in Figure 4.3 shows five distinct analysis stages and a brief description of these follows:

Stage I: Identify System SA sources

The aim of this stage is to validate or amend the generic SA Interaction Model (shown in Figure 4.2) for the specific system under analysis. A tailored System SA Model can then be produced to represent both the human and technical factors in the context of use and it is then used as a framework for developing an initial list of interaction hazards. It is clearly not practical to analyse all system interactions and this system model enables a Preliminary Hazard Identification (PHI) to be undertaken to consider SA-related interactions from a controller's perspective and to specifically identify those which are hazardous.

Stage II: Preliminary Hazard Identification

A PHI is undertaken in Stage II to focus the following analysis stages on the hazardous system interactions which are considered to be safety-related. The System SA Model validated in Stage I can be used during the PHI as the basis for the application of a HAZOP-based technique [MoD, 1995] to identify SA-related hazards.

Briefly, the aim of HAZOP is to identify, in a comprehensive and structured manner, the hazard and operability problems that may be associated with an operation, process or system. HAZOP is a widely used and well established hazard identification technique which is used in a range of industries [MoD, 1995]. The technique is particularly useful for the identification of operator or system errors which may lead to hazard or operability problems. A summary of the HAZOP process is given in Figure 4.4.

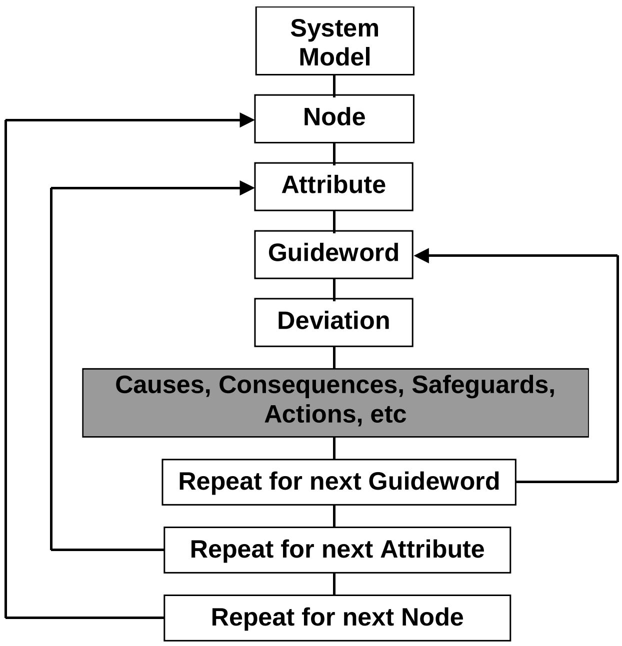

Figure 4.4 HAZOP Summary

The HAZOP technique involves a structured, systematic and comprehensive examination of designs or operations to identify potential hazard or operability problems. It can be seen from Figure 4.4 that a HAZOP begins with a system model (such as the System SA model) identifying the interconnections between nodes or components within the system and determining the corresponding interactions. These interactions may consist of the physical flow of material from one node to another or, for information systems, may represent the flow of data between components. Each system component possesses certain attributes denoting correct system operation, for example the *value or latency* of situation data may be important in a specific context. For each node, the effects of deviations from these attributes are considered using appropriate guidewords such as *inaccurate* or *none*. A HAZOP analysis will consider each system component or node in turn as shown in Figure 4.4. A detailed explanation of the HAZOP technique can be found in [MoD, 1995].

Stage III: Identify Hazardous Interactions

In this stage initial problem actions and operations resulting from interaction breakdowns are identified using the SA Process Model and applying the principles of Situated Interaction to direct the observation. The division of the SA Process model into different areas of operator activity (sample–modify–direct) provides a structure to analyse and categorise SA-related problems.

Stage IV: Analyse Hazardous Interactions

The aim of this stage is to analyse and describe the observed in-use interaction breakdowns using the SA Process Model and applying the Situated Interaction perspective as a guiding framework. The structure of the SA Process Model partitions different areas of interest and it enables the interaction boundaries between these partitions to be considered separately.

Stage V: Interpret Results and Suggest Safe Design Solutions

In this final stage, the findings from the preceding stages are interpreted. An understanding of the possible situated interaction breakdowns and their associated hazards will lead to informed re-design solutions which can be justified from a system safety perspective. Generally, SAPAT analyses concerning interaction breakdowns and automated interactions, deal with the design trade-off between usability and safety. SAPAT can therefore be used to identify those areas of an interactive system where safety should take precedence.

4.6 SAPAT and Safe Interactions

It has been suggested here that SAPAT can be used as a framework for the identification and analysis of hazards relating to operator awareness in the context of system use. Specifically, there are two ways in which SAPAT can contribute to the design of safer systems: identifying interaction breakdowns and identifying automatic interactions, both of which are key to SA. The hazards associated with these interactions can be related to the concepts of conscious and automatic cognition.

Differentiating between these two modes of cognition using SAPAT enables us to highlight and compare different aspects of human action which will be of use to the improved design of safety-related systems and this are discussed in the following sections.

4.6.1 Automatic Interactions

It is possible to use SAPAT to identify hazardous interactions which are carried out automatically without the operator modifying their awareness. If the specific interaction has been identified in the SAPAT PHI stage as hazardous, it is possible to design the system to prevent an automatic interaction. A simple example shows how this can be achieved. An Exit Menu used in a control system may ask the operator the final question:

"Are you sure you want to exit? Y/N."

Typically, such a system would use a Windows, Icons Menus and Pull Down (WIMP) style of interface and this particular interaction is often designed so that the operator can select with a mouse from two buttons marked either Yes or No which are always positioned in the same position relative to each other on screen. An analysis of this type of interaction would typically show that the action of selecting a button from the Exit Menu on a normal system shutdown will develop into an automatic operation without the operator being consciously aware of the interaction - until an erroneous menu selection is made.

This is an example of an *unplanned* automatic operation which is carried out without the conscious formulation of a plan. Reason [1990] asserted that the term *human* error could only be meaningfully applied to planned actions that fail to achieve their desired consequences without some unforeseeable intervention. It has been argued here that *system* errors can be caused through automated, unplanned operator interactions and these can be identified through the application of SAPAT. This example was not particularly hazardous in this context, however, a simple design solution to this may be to require a text string (not simply one keypress) in response to the question, "Are you sure you want to exit? Y/N." Forcing the operator to input a text string would increase the probability that the question is consciously considered a plan of action is formulated before the action is carried out.

There are also more subtle automated interactions that can lead to what Reason [1990] has called the Knowledge-Based Mistake. These automated interactions are ones where an interaction has developed from a conscious action to an automatic operation and SA-related information is not assimilated as a result. This can lead to incomplete operator awareness which, in a specific context, can result in the operator formulating the wrong plan and making what Reason [1990] calls a Knowledge-Based Mistake. To reduce the risk associated with these *planned* automatic interactions, it is again necessary to design the interaction to force it to become conscious to increase the probability of the operator's awareness being modified. Note, that it is only suggested here that this will increase the probability of the operator's awareness being modified as a breakdown may also occur during the Modifying Awareness stage of the SA Process Model due to a distraction for example.

4.6.2 Interaction Breakdowns

The SA Process Model used within SAPAT can also provide design guidelines relating to analysing difficulties that affect the user-system coupling, such as interaction breakdowns. The division of the model into areas of activity on the individual's part (sample–modify–direct) provides a structure to analyse and categorise SA-related problems. For example, the SA Process Model could be used to question where the problems in particular situations might have arisen: what information did the operator sample from their environment?; how did this lead them to modify their awareness (what information was available through the interface?); and how, subsequently, did this direct the operator's situated actions?

The structure of the SA Process Model partitions different areas of interest to allow system developers to concentrate on each as a distinct dimension contributing to awareness which can bring its own set of potential problems. It also permits a consideration of the interaction boundaries between these partitions, which is where many SA difficulties can be identified. As operators integrate sampled information, for example, the erroneous modification of their awareness may lead to an overall reduction in SA.

Clearly, substituting a text string input for a WIMPs button selection, as in the example above, will adversely affect usability metrics relating to the speed of interaction for example. However, for hazardous interactions identified in SAPAT Stage II, safety is more important and this leads to the following general design guideline for safety-related systems:

> *If an interaction is potentially hazardous, and the design will allow it to develop from a conscious action to an automatic operation, the design of the system should force the interaction to remain a conscious action [Sandom 2000, p.134].*

SAPAT analyses which identify interaction breakdowns and automated interactions can help systems designers to deal with the trade-off between usability and safety. SAPAT can be used to identify those areas of an interactive system where safety should take precedence [Sandom 1999]. For a detailed explanation of how SAPAT has been used for an exploratory analysis of interaction safety in a complex system where people in control can affect safety see Sandom [2000].

4.7 Conclusions

Developing an understanding of how the SA of an operator can be affected by the design of systems interactions within the context of use is an important safety issue and this was examined in this chapter. People in control of complex systems interact and operate using a remarkable cognitive process which requires the creation and maintenance of Situation Awareness (SA). However, there are many different definitions of SA and this chapter gave a review of the literature from which a Situated Cognition perspective was presented.

A system comprises both human and technical components and a comprehensive system model must therefore address both of these issues. An SA Process Model was introduced to model the process of a human operator acquiring and maintaining SA *in-situ*. A generic SA Interaction Model of a typical control system was also described which is based on a system's functionality and the SA-related interactions that can affect the operator. Together the SA Process Model and the SA Interaction Model constitute a generic System SA Model and this represents both the human and technical factors that can affect the SA of people in control.

In conclusion, the design of a control system will normally entail many trade-offs including the trade-off between safety and usability. During system development, human factors experts will often consult with the intended end users of the system who will invariably support the view that system interactions should be made ‘simple’ and ‘intuitive’. However, in the context of a system’s use, it may be hazardous for people in control to interact without consciously considering their actions and the SA Process Analysis Technique (SAPAT) was developed specifically to help systems designers to identify when safety should take precedence over usability.

4.8 References

Adams M. J., Tenney Y. J. and Pew R. W., ‘Situation Awareness and the Cognitive Management of Complex Systems’, Human Factors, 37[1], p.85-104, March 1995.

Billings C. E., Situation Awareness Measurement and Analysis: A Commentary, in Garland D. J. and Endsley M. R., [Eds.], ‘Experimental Analysis and Measurement of Situation Awareness’, Proc. of an Int Conf, FL:USA, November 1995.

Boehm B. W., ‘A Spiral Model of Software Development and Enhancement’, IEEE Computer, p.61-72, 1988.

Card S. K., Moran T. P. and Newell A., ‘The Psychology of Human Computer Interaction’, Lawrence Erlbaum Associates, Hillsdale, NewJersey, 1983.

Dominguez C., Can SA be defined?, in Vidulich M., Dominguez C., Vogel E. and McMillan G., [Eds.], ‘Situation Awareness: Papers and Annotated Bibliography’, 5-15, Report AL/CF-TR-1994-0085, Wright-Patterson AFB, Ohio, 1994.

Endsley M. R., ‘Measurement of Situation Awareness in Dynamic Systems’, Human Factors, 37[1], p.65-84, March 1995a.

Endsley M. R., ‘Towards a Theory of Situation Awareness in Dynamic Systems’, Human Factors, 37[1], p.32-64, March 1995b.

Endsley M. R., Theoretical Underpinnings of Situation Awareness: A Critical Review, in Garland D. J. and Endsley M. R., [Eds.], ‘Experimental Analysis and Measurement of Situation Awareness’, Proc. of an Int Conf, FL:USA, November 1995c.

Flach J. M.,‘Situation Awareness: Proceed with Caution’, Human Factors, 37[1], p.149-157, March 1995a.

Flach J. M., Maintaining Situation Awareness when Stalking Cognition in the Wild, in Garland D. J. and Endsley M. R., [Eds.], ‘Experimental Analysis and Measurement of Situation Awareness’, Proc. of an Int Conf, FL:USA, November 1995b.

Garland D. J. and Endsley M. R., [Eds.],’Experimental Analysis and Measurement of Situation Awareness’, Proc. of an Int Conf, FL:USA, November 1995.

Harris D.,[Ed.], ‘Engineering Psychology and Cognitive Ergonomics Volume 1: Transportation Systems’, Proc. 1st Int. Conf EP&CE, Stratford-upon-Avon, 23-25 October 1996, Ashgate Publishing, 1997.

Hopkin V. D., ‘Human Factors in Air Traffic Control’, Taylor and Francis, 1995.

Hutchins E., ‘Cognition in the Wild’, Bradford, MIT Press, 1995.

Issac A. R., Situation Awareness in Air Traffic Control: Human Cognition and Advanced Technology, in Harris D., [Ed.], ‘Engineering Psychology and Cognitive Ergonomics Volume 1: Transportation Systems’, Ashgate Publishing, 1997.

Kirwan B., Donohoe L., Atkinson T., MacKendrick H., Lamoureux T. and Phillips A., ‘Getting the Picture: Investigating the Mental Picture of the Air Traffic Controller’, Proc. Conf. Ergonomics Society, p.405-408, 1998.

Landauer T. K., Relations Between Cognitive Psychology and Computer Systems Design, in Carroll J. M., [Ed.], ‘Interfacing Thought: Cognitive Aspects of Human-Computer Interaction’, MIT Press, Cambridge: MA, 1987.

Mace W. M., Ask Not What’s Inside Your Head But What Your Head’s Inside Of, in Shaw R. E. and Brandsford J., [Eds.], ‘Perceiving, Acting and Knowing’, Hillsdale NJ, Erlbaum, 1977.

MoD, ‘A Guideline for HAZOP Studies on Systems Which Include a Programmable Electronic System, Draft Interim Defence Standard 00-58, July 1995.

Nardi B. A., [Ed.], ‘Context and Consciousness: Activity Theory and Human-Computer Interaction’, London, MIT Press, 1996.

Neisser U., ‘Cognitive Psychology’, New York, Appleton, Century-Crofts, 1967.

Neisser U., ‘Cognition and Reality: Principles and Implications of Cognitive Psychology’, San Francisco, W H Freeman, 1976.

Norman D. A., ‘The Psychology of Everyday Things’, New York, Basic Books, 1988.

Reason, J., ‘Human Error’, Cambridge, Cambridge University Press, 1990.

Sandom C, ‘Situation Awareness Through the Interface: Evaluating Safety in Safety-Critical Control Systems’, Proc. of IEE People in Control: Int. Conf. on Human Interfaces in Control Rooms, Cockpits and Command Centres, Conference Publication No. 463, University of Bath, 21-23 June 1999.

Sandom, C. W., ‘Situation Awareness and Interactive System Safety Analysis’, PhD Dissertation, Department of Information Systems and Computing, Brunel University, UK, March 2000.

Sarter N. B. and Woods D. D., ‘Situation Awareness: A Critical but Ill-Defined Phenomenon’, Int J of Aviation Psychology, 1, p.45-57, 1991.

Smith K. and Hancock P. A., ‘Situation Awareness is Adaptive, Externally Directed Consciousness’, Human Factors, 37[1], p.137-148, March 1995.

Suchman L., ‘Plans and Situated Actions’, Cambridge, Cambridge University Press, 1987.

Winograd T. and Flores F., ‘Understanding Computers and Cognition: A New Foundation for Design’, Norwood, Ablex, 1986.