SITUATION AWARENESS
SYNTHESIS OF LITERATURE SEARCH

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### Abstract:

This document is a first synthesis of the literature on the concept of Situation Awareness. In the light of the project, special attention has been paid to Situation Awareness measurement methods.
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1. INTRODUCTION

1.1. Background

Since the early 80s the study of ‘Situation Awareness’ has become an important area of research, especially in the U.S. Much literature has been generated on this subject proposing several definitions, models and assessment methods.

While some variance between the different definitions, models and methods exist, there is common agreement on the essential need for more and better knowledge and understanding of the subject.

“If human factors is to support ATM systems development, and ensure that the human continues to perform with high reliability, a better understanding of the picture, how it is built, maintained and lost is essential”. Barry Kirwan et al., NATS Hum Team.

In many, if not all, of the controller cognitive models, maintaining Situation Awareness is the core sub process, the basic background activity to air traffic control. “From a cognitively oriented point of view, this (maintaining S.A.) is the very core sub-process of ATM” (ITA phase 2 (draft)).

The importance of “background activity” is recognised as critical by ATCOs themselves. They refer to this phenomenon as “having the picture”. For controllers, “having the picture” is the first pre-requisite to handling their traffic; performing their task. “Losing the picture” is reported as one of the biggest risks for controllers as it is the source of several risks:

- The controller:
  - is no longer able to predict the evolution of the situation,
  - fails to detect – early enough - a problem or a conflict,
  - does not choose the optimum resolution, and in extreme cases
  - allows the creation of incidents or accidents.

1.2. Objectives

EUROCONTROL recognises that the concept of Situation Awareness is an important area of investigation. The aim of this research task is to provide a synthesis of available current thinking and writing on Situation Awareness. A further objective of the project is the publication of a guide for EUROCONTROL Project Leaders. The guide will advise how to be attentive to and conscious of Situation Awareness in projects from their very earliest stages.

This ‘Literature Search Synthesis’ is the first step of this process. It is a synthesis of the main theories and Assessment methods. It is not a critique, rather it is intended to describe the ‘state of the art’ i.e. current thinking on Situation Awareness.
2. DEFINITIONS

2.1. Boekle

Although Situation Awareness (S.A.) has only become a subject of intense research since the 80s, one of the first people to recognise and diagnose Situation Awareness and its importance was Oswald Boekle during World War I. As cited by Endsley (1988, 1995) Boekle realised “the importance of gaining an awareness of the enemy before the enemy gained a similar awareness”. Having observed this ‘awareness’ Boekle devised methods for accomplishing it.

2.2. Endsley

Universal agreement on a definition of Situation Awareness does not exist. However, the most frequently referred to definition is one proposed by Mica R. Endsley (1988). Situation Awareness is the “perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”.

Another definition by the same author (Endsley 1995) is also interesting and this definition is more explanatory and concrete: “Situation Awareness is based on far more than simply perceiving information about the environment. It includes comprehending the meaning of that information in an integrated form, comparing with operator goals, and providing projected future states of the environment that are valuable for decision making.”

For Mica Endsley there are three levels of S.A. elements. The three levels fit into each other. Mica Endsley created the following formula to depict this relationship.

\[
[(\text{Level 1 : Perception of the elements in the Current Situation}) \text{ Level 2 : Comprehension of the Current Situation } \text{ Level 3 : Projection of Future Status }] = \text{Situation Awareness}
\]

Level 1 : Perception of the elements in the current situation:

The first step in achieving S.A. involves perceiving the status, attributes and dynamics of relevant elements in the environment.

Level 2 : Comprehension of the current situation:

Comprehension of the situation is based on synthesis of disjointed level 1 elements. Level 2 S.A. goes beyond simply being aware of the elements that are present in the environment to include an understanding of the significance of those elements in light of the subject’s goals.
Level 3: Projection of future status:

This is the ability to project the future actions of the elements in the environment, at least in the short term. 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 S.A.)

2.3. Dominguez

Dominguez (1994) established a table of S.A. definitions:

<table>
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<th>Definition</th>
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<tr>
<td>Conscious awareness of actions within two mutually embedded four dimensional envelopes.</td>
<td>Beringer &amp; Hancock 1989</td>
</tr>
<tr>
<td>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.</td>
<td>Carroll 1992</td>
</tr>
<tr>
<td>The ability to extract, integrate, assess and act upon task-relevant information is a skilled behaviour known as “Situational Awareness”.</td>
<td>Companion, Corso, Kass &amp; Herschler</td>
</tr>
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<td>The accurate perception of the factor and conditions that affect an aircraft and its flight crew.</td>
<td>Edens 1991</td>
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<tr>
<td>The accurate perception of the factor and conditions that affect an aircraft and its flight crew during a period of time.</td>
<td>Schwartz 1993</td>
</tr>
<tr>
<td>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.</td>
<td>Endsley 1990</td>
</tr>
<tr>
<td>The knowledge that results when attention is allocated to a zone of interest at a level of abstraction.</td>
<td>Fracker 1988</td>
</tr>
<tr>
<td>The pilot’s overall appreciation of his current “world”.</td>
<td>Gibson, Garrett 1992</td>
</tr>
<tr>
<td>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.</td>
<td>Haines &amp; Flateau 1992</td>
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<td>Where refers to spatial awareness … What characterises identity awareness, or the pilot’s knowledge of the presence of threats and their objectives, [as well as] engine status and flight performance parameters. Who is associated with responsibility, or automation awareness; that is knowledge of who is in charge. Finally, When signifies temporal awareness and addresses knowledge of events as the mission evolves.</td>
<td>Hardwood, Barnett &amp; Wickens, 1988</td>
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<td>The ability to envision the current and near-term disposition of both friendly and enemy forces.</td>
<td>Masters, McTaggart &amp; Green 1986</td>
</tr>
<tr>
<td>Awareness of conditions and threats in the immediate surroundings</td>
<td>Morishige and Retelle, 1985</td>
</tr>
<tr>
<td>The ability to maintain an accurate perception of the surrounding environment, both internal and external to the aircraft as well as to identify problems and/or potential problems, recognise a need for action, note deviations in the mission, and maintain awareness of task performed.</td>
<td>Prince &amp; Salas 1993</td>
</tr>
<tr>
<td>S.A. 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.</td>
<td>Regal, Rogers &amp; Bouceck 1988</td>
</tr>
<tr>
<td>Situation Awareness refers to the ability to rapidly bring to consciousness those characteristics that evolve during flight.</td>
<td>Wickens, 1992</td>
</tr>
<tr>
<td>The pilot’s knowledge about his surroundings in light of his mission’s goals.</td>
<td>Whitaker &amp; Klein 1988</td>
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Considering all of the definitions in above table, Dominguez established the following points that should be addressed in a comprehensive definition of S.A.:

“extracting information from the environment; integrating this information with relevant internal knowledge to create a mental picture of the current situation; using this picture to direct further exploration in a continual perceptual cycle, as well as to anticipate future events.”

Keeping these points in mind while reviewing all of the existing definitions, Dominguez proposes the following definition:

“S.A. is the continuous extraction of environmental information, the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception, anticipating future events”

2.4. ATM Human Resources Unit, EUROCONTROL

The definition adopted by the ATM Human Resources Unit at EUROCONTROL Headquarters can be considered as a grouping of the definitions of Endsley and Dominguez:

“The perception of the elements in the environment within a volume of time and space, comprehension of their meaning and the projection of their status in the near future. This also means the continuous extraction of environmental information and the 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. Situational Awareness is established by a continuous comparison between anticipation (predicted state of the system) and environmental input (actual state of the system)”

2.5. Ochanine

In the late 60s, Ochanine defined certain properties of the human mental picture. Based on the results of his experiments, he theorised that this mental picture is not an isomorphic duplication of reality, rather it is transformed according to certain rules. He called such a transformed image an "operative image".
An operative image is not an exact replica of reality, it is:

- partial: all the elements of reality are not represented;
- distorted: emphasis is placed on the information relative to the task’s objective's,
- functional: shaped by the objectives of the subject and the task.

In terms of Situation Awareness, a "good mental picture" could be partial and distorted with regard to reality (objective reality). Transforming the reality in such a way is highly risky and might generate errors, however the transformation gives a richness and a perfect adaptation to the subject and his/her ongoing activity.

Later, due to the process of building and transformation, the term picture was abandoned by many researchers and replaced with the term "mental representation". We now use the term "operative mental representation".

2.6. Grau, Menu & Amalberti

On the basis of studies not only in the field of aviation but also in different process industries, Grau, Menu & Amalberti (1995) describe S.A. according to three main characteristics:

Situation Awareness appears to be an individual and personalised construct. An analysis of the activity of 8 pilots performing the same mission showed that none of the pilots performed the mission in the same way. Not one of them had the same perception and understanding of the situation.

It is difficult to define ‘good’ and ‘bad’ S.A. In the previously quoted study the 8 pilots all succeeded in performing the mission (albeit in different ways). It could then be hypothesised and argued that there are “several states of good S.A.”.

Finally, there is a relationship between S.A. and time constraints. Several of the researches quoted in this article have shown that an operator has several different ways of performing the same task depending on the accompanying level of time pressure.

From these observations the authors found it reasonable to propose several "levels" of S.A. based on (coupled with) levels of time pressure.

2.7. Team Situation Awareness

But should S.A. only be considered as an individual construct and on an individual level?

Some researchers disagree and feel S.A. could and should be considered at the level of the Team.

However, as underlined by Stout, Cannon-Bowers & Salas (1996-97) “there has been insufficient attention paid to the construct of Team Situational Awareness ... Indeed, a review of the literature reveals that no clear definition of Team Situational Awareness has
been provided. This lack of definitional clarity is not trivial in that it hinders the cumulation of knowledge in this area.”

Endsley (1995 a) did address Team S.A. and proposed the following definition: “One can conceive of overall team S.A., whereby each team member has a specific set of S.A. elements about which he is concerned, as determined by each member’s responsibilities within the team. Some overlap between each member’s S.A. will be present. It is this subset of information that constitutes much of team co-ordination. The information in the overlap area needs to be known by all the concerned members. It may constitute verbal exchange or separate direct viewing of display. Higher level of S.A. may be communicated verbally or, if the team members possess a shared mental model each team member may achieve the same higher-level S.A. without necessitating extra verbal communication.”

The findings of research studies indicate that when considering Team S.A. it is essential to examine team interaction.

Results of studies conducted by Prince, Stout & Salas (1994) provided evidence that a more comprehensive S.A. i.e. “a bigger, better picture” was provided by collective feedback of the team than was provided by individual feedback from all the members of the same team. “Team S.A. is thought to be more than the sum of individual S.A. of the team members”.

Studies by Cook, Stout & Salas (1997) showed that each individual creates his/her own individual and personal knowledge base. When these knowledge bases are combined, as happens during teamwork, a broader and more complete knowledge base is created. “Individuals may each possesses accurate mental models but what is relevant for team S.A. is how various individual knowledge interact”

After a review of the different studies made on Team S.A., Stout et al. (1996-97) made the following assumption: “Taken together, the work on Team S.A. has several implications:

1) existing Mental Models shape individual S.A.;

2) shared Mental Models seem to be critical to team performance because they allow each member to form adequate explanations and expectations of task and team actions; and

3) team S.A. enhances team performance”

The majority of the limited studies on Team S.A. assess it via communication.

We can identify the limitations of this method and agree with Stout et al. (1996-97) “one cannot be certain of whether S.A. was truly lacking or simply not talked about”.

More critical than the overlap of Individual S.A., Stout et al stress that to enhance Team S.A., it is crucial that the knowledge of members of the team is compatible.
3. S.A. AND THE DIMENSIONS OF COGNITIVE ACTIVITY

3.1. Mental Model and S.A.

S.A. is an internal construct and is also part of the overall cognitive activity of the controller. S.A. is influenced and in return influences other psychological constructs.

3.1.1. The Mental Model

An important concept is the Mental Model. The Mental Model has been defined as “the cognitive processes / representations whereby humans are able to generate descriptions of system purpose and form, explanation of system functioning and observed states and predictions about future system state” (Rouse and Morris 1986, in the EATMP Documents, ATM Human Resources Unit, EUROCONTROL Headquarters).

Mogford (1994) extended this definition “A mental model is an organised set of knowledge that has depth and stability over time. It is different from knowledge in general in that the term model suggests the formation of a conceptual analogue of the external world to understand and predict system behaviour”.

3.1.2. Long Term Memory

The Mental Model is stored in Long Term Memory “...is one of the four components of the structural model of the cognitive processes of ATC. It stores the mental model structured information (Knowledge); information-processing routines and programmes.” (ATM Human Resources Unit, EUROCONTROL Headquarters)

In the case of a controller, Long Term Memory will store generic knowledge about Air Traffic Control, e.g. about sectorisation as well as personal professional experience gained.

This would correspond to Mogford’s description of the “domain model” to which must be added, according to Mogford, a “device model” “which is an understanding of the electronic systems (including computer – human interface) designed to support ATC” (Mogford 1994).

According to the current task goal or subgoals, the Mental Model will direct the attention of the subject to key features in the environment, influencing the perception of the elements of the current situation: Level 1 S.A. In other words, an individual’s preconception and expectations about information will affect the speed and accuracy of the perception of that information.

If a controller has a “good” Mental Model, comprehension of the situation (Level 2 S.A.) will be achieved by matching the present situation with a generic situation. In the absence of an efficient Mental Model, the processing of information, its combination with existing knowledge will occur in the Working Memory.
3.1.3. Working Memory

“Also known as short-term memory, working memory stores information currently being used or attended to. It has a capacity of between five to nine “chunks” of data at any one time, and data not attended to is lost within about 30 seconds. Skilled representations and mental models are active in working memory when used to support task performance”.

A well-developed Mental Model is hypothesised to provide a mechanism for projecting future state of the system. (Level 3 S.A.) (ATM Human Resources Unit, EUROCONTROL Headquarters)

“The key to using these models to achieve S.A. rests on the ability of the individual to recognise key features in the environment that will map to key features in the model. The model can then provide for much of the higher levels of S.A. (comprehension and projection) without loading the Working Memory”. (Endsley 1995 a)

Differences between novices and experts (see chapter 5 Nissan, Eyferth & Bierwagen 1998) can be explained by the lack of an efficient Mental Model i.e. for the novices a Mental Model is still in “construction”.

S.A. will then form the basis of the decision-making process and, as an ongoing process, will be updated by the feedback of action and / or the “natural” evolution of the environment. S.A. should also be used in return to enrich or modify the representation of the generic situations within the operator’s Mental Model.

“In ATC, the Mental Model is the underlying knowledge that is the basis for S.A. or the picture. The controller’s picture is defined by the mental model and, in turn, supplies information to build and modify it … … Data from auditory or visual displays are momentarily perceived, stored in S.A., and may update the Mental Model if there are long-term implications. Information in the Mental Model influences and structures the data held in S.A. and directs attention.” Mogford (1994).

S.A. can in this regard be regarded as a little loop (maintaining awareness of the situation) inside / part of a bigger loop (maintaining abilities to perform the job).

3.2. S.A. and internal factors

S.A. and Stress:

Stress, physical or psychological, can have a different (or opposite) effect on the achievement of a good S.A. A certain amount of stress can be beneficial to S.A. It can enhance attention to the critical cues of the situation. A higher level of stress can have the opposite effect and the operator will tend to narrow his/her field of attention, and focus on dominant or probable sources of information. This is the “cognitive vision tunnel” described by Sheridan.

Like Endsley (1995 a) we see in this phenomenon a critical problem for S.A. for in many unusual (“non routine”) cases it is the factors which are outside of the operator’s cognitive vision tunnel that prove to lead to errors.

Another effect of perceived stress is an incomplete or partial exploration or all the information available in order to gain time.
3.3. S.A. and Workload:

The research findings of Endsley’s indicate no dependence between Workload and S.A.:

**Low S.A. with low workload:** can be due to inattentiveness, vigilance problems, or low motivation.

**Low S.A. with high workload:** volume of information and number of tasks too great, operator can only attend to a subset of data, could lead to erroneous or incomplete perception and integration of information.

**High S.A. with low workload:** required information could be presented in a manner that is easy to process. This case can be considered as ideal because the operator has a good awareness of the situation combined with plenty of spare resources.

**High S.A. with high workload:** the operator is working hard but successfully achieving an accurate and complete picture of the situation.

It would be interesting to further explore the relationship between S.A. and workload by studying the effect of workload variation on S.A.

Hallbert (1997) held simulator-based studies of S.A. in the field of nuclear power plants. One of the findings was “The greatest drop in S.A. occurred during the period of workload transition, that is from normal to abnormal conditions. Thereafter, S.A. recovers, even though workload remains high. The explanation of the relationship is further complicated by the downward trend in S.A. observed at the end of the scenario.”
4. EFFECTS OF AUTOMATION ON S.A.

S.A. problems observed with automation have been directly linked to several major factors (Endsley and Kiris 1995): Assuming a monitoring role under automation can have the following effects:

- loss of vigilance
- increase in complacency
- change from active processor to passive recipient
- loss of or a change in the type of feedback

An increased level of complexity associated with many automated systems often results in additional parameters that can interact in more complex ways and a combination of circumstances that may rarely be seen (therefore more difficult to recognise and to deal with).

Possible loss/reduction of skills with automation may provoke difficulties should a degradation of the technical system occur.

On the other hand, Wiener (1992) pointed out that S.A. might be enhanced with automated systems. Automated systems that can provide superior, integrated information to operators. In addition, automation may improve S.A. by a reduction of workload.

However, describing what she termed as the irony of automation Bainbridge (1983) found that when workload is highest, automation is often of least assistance! Reductions in workload, which are assumed to accompany automation, have not necessarily been realised. Automation often replaces workload involving physical activity with workload involving cognitive and perceptual activity.

It should be stressed that the activity of Air Traffic Controllers is already highly perceptual and cognitive.

Levels of Automation

An alternate approach to automation focuses on enhancing operator S.A. by keeping him/her involved in the task. This is achieved by determining a level of automation that minimises negative impact on operator S.A. Usually 10 levels of automation are identified - from fully manual task to full automation via different divisions between man and machine. At an intermediate level of automation the human may be far more involved in the operation of the system than at high levels of automation. S/he is then able to deal more effectively with the automated system when needed.

Three studies presented by Endsley (1997) [(Endsley & Kiris 95) (Endsley & Kaber 96)] show that even though full automation of task may be technically possible, it may not be desirable, if the performance of the joint human-machine system is to be optimised. Intermediate levels of automation may be preferable in order to keep human operators’ S.A. at a higher level and allow them to perform critical functions.

In 1994, a panel was convened by the National Research Council (USA) and the FAA, to examine the issue of air traffic control automation. The panel contained 2 experienced controllers and spent 3 years studying ATC systems. The main recommendations from this panel are reported in an article by Wickens (1998): “Automation in ATC: the Human Performance Issues”.


The group used the Levels of Automation described by Endsley but “…found it necessary to expand the concept of levels into three different “human-centred” scales of automated functionality, corresponding approximately to the human processing functions of
1) Information Integration to maintain Situation Awareness (through attention, perception and inference);
2) choosing and deciding upon actions, and
3) executing those actions …

In general, we recommend that high levels of automation be pursued for information integration, as long as these processes are reliable. We recommend only intermediate levels for decision choice, if such decision involve risk and we recommend high levels of automation for response execution, as long as automation choice levels are not high.”

“Across all three functions - attention, integration, and inference- human performance data support the conclusion that higher levels of automation, supporting higher levels of S.A. are of near universal benefit, as long as such automation is reliable. … Careful task analysis can insure that highlighting and attentional cueing will guide users to the most relevant information, while low-lighting or backgrounding of less relevant information, will still make that information accessible should it be unexpectedly needed.” “ However, if attentional filtering and inference making are less than perfectly reliable they will induce costs (when wrong) along with benefits (when right).”

Thus the cost/benefit analysis is of critical importance.

In this article Wickens cites four different experiments with common findings i.e. that “humans may follow and believe unreliable automation even as the latter conflicts with evidence visible to their own eyes… The human factors research that is critical to address this issue, is how to design displays that can intrinsically signal the level of unreliability of the cueing or inference, in order to avoid the syndrome of over trust by the user (and hence perhaps avoid an overreaction to mistrust once the unreliability has been noticed)”

Another solution might be the regular return to non-automated practice session as a kind of permanent training. This is presented by Daniellou (1986) as the best way to keep the operator’s representation at a level allowing the treatment of unusual situations, and the ability to cope should a partial degradation of the technical system occur.
5. S.A. AND SYSTEM DESIGN

Maintaining S.A. has been identified as a critical process. It is recognised by most, if not all, the proposed models of ATCOs as the basis for other process. Losing S.A. or “losing the picture” is considered by ATCOs themselves as the biggest danger to safety or error occurrence.

As stated in the introduction, one of the objectives of this project is to provide information on methods which will allow designers of new systems to incorporate S.A. guidelines from the earliest design stages.

This objective is as ambitious as it is critical. As stated by Smith, Woods et al. (1998) “Changing roles by re-distributing authority (locus of control) has strong implications for the kinds of information and information displays needed to support these new roles. New ATM concepts change the roles of many of the people involved in the system… If the changes created by these shifts in the locus of control, and in decision concerning whether and when to intervene, are not accompanied by a corresponding shift in access to information, problems can arise”

Endsley’ recommendations

Mica Endsley (1995) established a set of recommendations regarding system design.

(Reminder: These recommendations refer to her model in which S.A. is composed of three levels of elements: Level 1 S.A.: elements of current situation, Level 2 S.A.: comprehension of the situation, Level 3 S.A.: projection of future status):

As working memory is limited: provide information that is already processed and integrated in terms of Level 2 and Level 3 S.A.

Information needs to be S.A. oriented i.e. information needed for a particular goal is collocated and directly answers the major decision associated with the goal.

Critical cues for activating mental models and schemata need to be determined and made salient.

Salient design features should be reserved for critical cues that indicate the need for activating other goals and should be avoided for non-critical events.

Problem when attention is focused on a subset of information: provide global S.A. – an overview of the situation across operator goals – at all times while providing detailed information as required.

The filtering of extraneous information (not related to S.A. needs) and reduction of data (by processing and integrating low level data cf. 1) should be beneficial to S.A. (however, this implies an extremely good knowledge of global S.A. requirement, as filtering implies the risk of “erasing” cues that might be critical)

One of most difficult parts of S.A. is the projection of future states of the system: system generated support for projecting future events and states of the system should directly benefit Level 3 S.A., particularly for less experienced operators.

System designs that support parallel processing of information should directly benefit S.A. For example, the addition of voice synthesis or three-dimensional audio-cues to the visually overloaded cockpit is predicted to be beneficial on this basis.
Grau & Amalberti’s recommendations

In their 1995 article on Situation Awareness in combat aircraft, Grau & Amalberti make recommendations to enhance S.A. These recommendations, made in the field of aviation and dealing with enhancing Pilots’ S.A., can be generalised and applied to Air Traffic Controllers.

The first concept is to present information according to their representation in the subject’s S.A. Data should be provided in a format compatible with the pilot’s logic of use rather than with the technical system’s logic.

A second concept is to provide the pilot with all, and only, the necessary information. The authors recognise that this is a challenge. The main reason for (partial) failure during past attempts has been attributed to the difficulty of capturing expert knowledge. In fact, a large amount of this knowledge is not conscious due to automatic processing or implicit learning.

Another further recommendation is to provide the operator with supporting tools. The objective is to highlight to the pilot (or controller) some aspect of the situation that s/he would have forgotten or underestimated. It is essential that the operator has a good mental representation of the system (technical system) to avoid any shocks and to allow him/her to trust the tools.

In order to enhance the operator’s S.A., the technical system must also be capable of anticipation “a reactive system would be of no help” (Grau & Amalberti, 1995)

In order to apply the above-mentioned recommendations, S.A. requirements should be taken into account not only when developing the HMI but from the very beginning of project definition.
6. KEY S.A. ELEMENTS FOR AIR TRAFFIC CONTROLLERS

Several studies on Controllers’ Mental Representation have been carried out in France since the late 60s. A synthesis can be found Bisseret’s “Représentation et Décision experte, psychologie cognitive de la décision chez les aiguilleurs du ciel”. In accordance with Ochanine’s theory the results confirm the functional distortion and the cognitive economy of the Controllers’ representation.

Main findings of research studies

Controllers do not consider aircraft in isolation, rather they consider aircraft in couples of aircraft: the related data (S.A. elements) are then relative data e.g. “this aircraft is at a higher level than this one” rather than “individual levels”. This point was re-examined years later (late 80s; early 90s) by several research studies reported in Gronlund et al. (1998) “For example, two aircraft crossing at the same altitude is a problem, regardless of the altitude. Consequently, rather than encoding that AAL123 is at FL230 and that SWA456 is at FL270 perhaps controllers encode only the “gist” (i.e.: SWA is higher than AAL)” Some errors can occur regarding individual data but the relationship between 2 aircraft might nevertheless be correct.

Cognitive economy: it was confirmed that controllers only consider the data needed to make decisions. Position and altitude are considered as two key data. It is only when information on position and altitude are not sufficient for conflict detection that the controllers look for other sources of information.

Controllers operate in predictive mode: in a great majority of cases when the value of these two dimensions (position and altitude) are not reported correctly, it is because the controller was operating in a predictive mode i.e., anticipating the situation and working ahead e.g. reporting position and altitude of aircraft in +2 minutes.

Functional distortions have also been found in the representation of the airspace and map: these distortions are highly correlated with the frequency of traffic load on those elements.

Differences can occur depending on ATCO experience (Nissan, Eyferth & Bierwagen 1998): The experienced controllers’ picture is based on less, but more relevant, information. In contrast, inexperienced controllers analyse more traffic information in general. At early stages of conflict detection the inexperienced controllers focus on every aircraft, where experienced controllers focus on the basis of particular features (i.e. a/c located near to each other, vertical movement or points in the space with higher probability of conflict ..) and classify the a/c into two groups: those requiring further analysis and those which can be separated safely immediately.

Rodgers (1994) provided a long list (more than 20 pages) of S.A. requirements for En-Route Air Traffic Controllers. The list is presented in a hierarchical format and resulted from the findings of a Goal Oriented Task Analysis. Rodgers lists the controller’s main goal, associated sub-goals and situation awareness requirement for meeting these sub-goals. This analysis does not address the question of the information support i.e. how a controller would get the information. Rodgers presents all the information that could possibly be required by a controller to meet each sub-goal in an ideal world. This list as it stands cannot be of primary and direct help for the system designer. Unfortunately, a means of exploitation has still to be found. This weakness is due to the fact that no weighting is attributed to the elements of this very detailed description.

Three other lists of elements or “S.A. requirements” are presented in Annexe B.
However, a problem identified with these latter lists (the concept itself of S.A. element lists) is that all elements have the same weighting and importance. The change of importance and weighting of each element has not been described: not all elements have equal importance at all times. Maintaining S.A. is a dynamic process and the importance of one element will vary, becoming secondary at certain points in time. Moreover, the inter-relation of the elements themselves and the dynamic changes seem critical to assess the complexity and richness of the concept of S.A.

Results of an experiment held by Mogford (1994) with ATC trainees suggest that “…certain Level 1 S.A. aircraft data are more critical than others … Although it might be expected that all aircraft information is critical for adequate air traffic controller S.A., this experiment demonstrates that some elements (e.g. aircraft altitude and heading) may play a key role, whereas others (e.g. speed, position and identifier) may not be as important as expected….There may be three kinds of data in the ATC environment: a) that which must be remembered and updated; b) that which can be searched for when needed and forgotten; and c) that which can be ignored. Only the first type of data is retained in S.A.”
7. LOSS OF S.A. / EVENTS (DATA) IMPAIRING S.A.

Losing S.A. is a very stressful experience and controllers are very careful to avoid such an occurrence.

Before loss of S.A. some of the following elements/events can and must be taken as indicators of an ongoing impairment of S.A.

- inconsistency in communication with pilots, colleagues, adjacent sectors or Centre;
- sudden and unexpected variation of workload;
- confusion;
- unexpected events;
- repeated need to check up on a same information.

The following elements were identified as impairing S.A. (making the picture difficult to maintain) by the NATS HUM team. The method used in this research was Picture Interview

- distractions from people controllers are working with;
- noise/distraction;
- volume of traffic;
- number of phone calls;
- aircraft calling in too early;
- lack of strip information at the right time;
- too much happening and having to process too much information;
- traffic building up;
- unusual or unexpected events;
- radar outage;
- getting behind on tasks; (cause or consequence ?)
- becoming reactive rather than proactive. (cause or consequence?)

Effects of Automation already mentioned in chapter 4.

In addition to situational conditions, an impairment of S.A. can be experienced when controllers have been out of work for several weeks. Routines and automated action are degraded. Controllers report that usually when they return to work, they try to start with a "calm position" where the demands are not too high. (ITA, phase 2, Proposed issue)
8. ERRORS AND S.A.

Even if a good level of S.A. is not a guarantee of good performance, it can be hypothesised that a poor S.A. will increase the risk of error occurrence.

Errors related to S.A. can be described according to Endsley’s three levels.

Errors can occur due to either incomplete S.A.: i.e. knowledge of only some of the elements; or inaccurate S.A.: i.e. erroneous knowledge concerning the value of some elements or the integration of those elements.

A person may simply fail to perceive information that is important for building a good S.A. with regard to the assigned task. Endsley talks then about Level 1 S.A. errors: Failure to correctly perceive the situation.

Level 1 S.A. errors can be due to a lack of salience of a critical cue, a physical obstruction or a failure of the system to make the information available. But Level 1 S.A. errors can also be caused by an overabundance of information or lack of adequate strategy to direct the information sampling.

In 1996, Jones and Endsley (Endsley & Smolensky 1998) conducted a study of incidents involving reported problems in NASA's voluntary reporting system. Of the 33 incidents reported 69 % involved problems with Level 1 S.A. The most common problem was failure to monitor or observe data. This was most frequently due to task distraction.

Level 2 S.A. errors correspond to a failure to properly integrate or comprehend the meaning of perceived data in light of the operator’s goals. In the above-mentioned study from Jones and Endsley, Level 2 errors were attributed to an incomplete mental model, the use of an incorrect mental model and over-reliance on default value.

Level 3 S.A. errors: even if a situation is clearly understood, it may be difficult to accurately project future dynamics without a highly developed model. According to the analysis of the reported problems more than 33% of Level 3 S.A. errors were attributed to the over-projection of current trends.

In their article on Operational Errors S.A. Durso et al. (1997) stated that non-technical causal factors were about to be included in the official Operational Error Reports. Among the questions related to these non-technical factors, Situation Awareness questions are directly inspired from Endsley’s levels: i.e. perception, comprehension and prediction. The authors were concerned about the ease and reliability with which QA specialists¹ could make this distinction: "For example, when we attempted to classify our 388 reports using trained student observers, agreement was quite low (less than 50%). It was especially difficult to distinguish between comprehension and prediction. We remain cautiously optimistic that professional controllers would more easily make decisions among the three Situation Awareness classifications”

Currently, in official Operational Error Reports, questions related to the three S.A. Levels appear under the category of “Inappropriate Use of Displayed Data" and allow the investigator team to check off whether causal factors contributing to the incident were:

- Failure to detect displayed data,
- Failure to comprehend displayed data, and/or
- Failure to project future status of displayed data.

¹ Quality Assurance specialists
The inclusion of these items reduced the frequency of use for "Other" under this category, suggesting that their inclusion is relevant and allows precision. However, there are still concerns about how informative this information is as it is currently reported.²

**Awareness of Errors**

Several research studies have suggested that controller awareness of error development was related to the severity of Operational Errors as reported in an article from Rodgers Mogford & Mogford (1995). Rodgers & Nye found that controller awareness of error development was associated with less severe errors.

Rodgers, Mogford & Mogford (1995) studied a sample of 85 operational errors covering a three year period from June 92 to June 95 for the Atlanta ARTC Centre. Characteristics of the operational errors were analysed with regard to the awareness or non-awareness of the controllers and also with regard to the complexity of the sectors and sector error rates.

One interesting finding was that even if greater separation existed for both the vertical and horizontal dimensions for errors of which the controller was aware, the difference was only significant for the horizontal component. An explanation proposed by the authors is that altitude, used to provide vertical separation, is reported numerically in the data block. Thus, altitude information is more likely to be more salient than the information used to make a judgement about the extent of horizontal separation between aircraft.

The other main finding was that awareness of error development was significantly correlated with sector error rates: controllers involved in operational errors at sectors that have greater error occurrence tend to demonstrate less awareness of the developing error. The authors make the hypothesis that low awareness, presumably influenced by sector complexity, leads to higher operational error incidence.

Durso et al. (1997), in an analysis of data for a one year period (1993) confirmed that controller awareness of error development resulted in significantly less severe errors.

"unaware controllers made significantly more severe errors than did aware controllers with the former having aircraft fly 1.5 nm closer than did the latter" In this study, unaware controllers made more errors than aware controllers in the two dimensions - lateral and vertical. Aware controllers tended to make more thinking errors (e.g. judgement, assumption), whereas unaware controllers tended to make memory and perceptual errors (e.g. read back altitude errors). The discrimination between the type of errors appears to be the critical element impacting the severity of errors. "Thus, unaware controllers were more likely to make the type of errors that gave rise to more severe communications errors. However, when aware controllers did make these types of errors, they too experienced a severe loss of separation".

² An FAA research project is currently addressing this question.
9. S.A. MEASUREMENT METHODS

9.1. Query techniques

9.1.1. SAGAT Situation Awareness Global Assessment (Endsley):

“The Situation Awareness Global Assessment Technique (SAGAT) is a global tool developed to assess S.A. across all of its elements based on a comprehensive assessment of operator S.A. requirements” (Endsley 1995b)

The simulation is frozen at randomly selected times and subjects are queried as to their perception of the situation at the time (queries on specific data or data criteria).

The rationale behind the use of the freezing technique is that it is a way to overcome the limitations of reporting on S.A. after the fact (memory limitation, re-construction, and tendency to over-generalise…).

The reasoning behind the randomly selected times of breaks is that it will not be possible for the subject to mentally prepare for the queries by attending to more information or memorising variables. Temporary halts in the simulation represent the primary disadvantage of this technique.

As it is impossible to query a subject about all of his/her S.A. elements (“requirements”) due to time constraint, a portion of the S.A. queries are randomly selected and asked at each stoppage. The fact that some queries may address information of secondary importance at the moment of a given stop is considered to avoid the artificial direction of the attention of the subject when the simulation is resumed.

Depending on the objective of the experiment and of the technical system evaluated certain queries will be presented every time while some others will be omitted because they are considered as not relevant. “For example, if the simulation does not incorporate aircraft malfunctions the query related to this issue will be omitted”.

For ATCOs the first query will always (i.e. at each stop) address the position of the aircraft in the controlled sector. An appropriate sector map is presented and the subject is required to enter the location of all aircraft within the sector and area immediately surrounding it.

Subjects’ responses are then compared with the actual situation according to the simulation computer database (screen dump) to provide an “objective measurement” of S.A.

As some of the queries refer to a high level of S.A. requirement (i.e. Level 3 = projection of future status in Endsley’s model) an experienced observer will be needed to make an expert judgement at each stop. “The Expert judgement should reflect the S.A. of a person with a “perfect” knowledge of the situation."

“The comparison of the controller’s perceptions of the situation (as input to SAGAT) to the actual status of each variable (as collected per the simulator computer and expert judgement) results in an objective measure of S.A”.

Endsley claims that this method is not intrusive. However, stoppage involves the disruption of the natural flow of the task and the aforementioned artificial aspect must question this claim.
“The most important problem associated with this technique is that halting the simulation and prompting the pilot for information concerning particular aspects of the Situation is likely to disturb the very phenomena the investigator wishes to observe” (Sarter & Woods 1995).

Even if the queries are asked randomly (some queries will not be random) it does not always prevent the attention of the controller being artificially oriented when the exercise resumes.

The principle of comparison with the operational situation does not seem to take into account the natural and operational distortion highlighted by Ochanine. Comments of Gronlund et al. (1998) agree with Ochanine, these authors concur that all aircraft being considered equivalent is a limitation. We believe that there are some aircraft about which little was remembered: “the controller should remember more, and other aircraft for which it would be acceptable that considered equivalent is a limitation. We believe that there are some aircraft about which Gronlund et al. (1998) agree with Ochanine, these authors concur that all aircraft being accounted the natural and operational distortion highlighted by Ochanine. Comments of The principle of comparison with the operational situation does not seem to take into prevent the attention of the controller being artificially oriented when the exercise resumes. Even if the queries are asked randomly (some queries will not be random) it does not always prevent the attention of the controller being artificially oriented when the exercise resumes.

Like Mogford (1995) we agree that. “A potential problem emerges when comparing the data reported by the operator to the actual values presented at the time of the simulation interruption. Should a response be counted as correct only if it is exactly the same as the real value?” This problem is alleviated somewhat by the existence, but only for few queries, of an “acceptable tolerance band around the actual value”.

This method is helpful to know which data are taken into account, in fact perceived and memorised, at a time: the WHAT; but is limited on the explanatory aspects: the WHY. SAGAT, as indicated by its name, allows an Assessment of S.A., which implies that this S.A., for a specific task, is already delineated, determined and its elements precisely identified.

Convinced by Amalberti’s statement that: “the quality of the representation cannot be measured in terms of amount of data taken from the situation” we do think that SAGAT is of interest if used in association with methods which allow for a value, or weighting, to be applied to the resulting data.

Values and weightings could be “calculated” by interviewing Subject Matter Experts. One interesting method to achieve this is suggested by Mogford (1995); for him it would be preferable to start by an evaluation of skilled controllers’ representations of aircraft and their attributes (using SAGAT). This is based on the assumption that the skilled operators used in these evaluation have, by definition, sufficiently accurate S.A. to perform their tasks; it would then be possible to build a database and establish tolerance limits for Level 1 S.A. elements.

As this technique necessitates task interruption it can only be used in simulated environments.

SAGAT is the most widely know Query Technique and other techniques have been derived from it: e.g. SACRI (Situation Awareness Control Room Inventory) used in experiments for nuclear power plants.

Annex A contains an example of SAGAT queries.
9.1.2. SPAM: Situation-Present Assessment Method (Durso & Al. 1995, Durso & al. 1998)

SPAM is another query technique. It does not use the freezing method; queries are very similar to SAGAT queries but all information normally available to the subject remains in view. The data collected and analysed (the dependent variable) is not the percentage of correct answers but the time (delay) elapse between the query and the answer.

“Although SPAM is procedurally similar to SAGAT, the two differ in interesting ways. In addition to not requiring a memory component, SPAM acknowledges that S.A. may sometimes involve simply knowing where in the environment to find the particular piece of information, rather than remembering what that piece of information is. For example a controller need not store in memory the call sign of an aircraft, but good S.A. may require that he or she knows where to find the call sign should communication with the aircraft be required” (Durso et al., 1998). The queries are asked to the controller via his/her landline. The assumption is that this “input mode can be fit into the controller’s existing work scheme” (Durso et al., 1995). After the participant answers the landline, the experimenter reads the question and initiates a timer. When the controller answers, the timer is stopped and the delay and the responses are registered.

An argument for not using the freezing technique is that any technique that removes controllers’ attention from their radar screen is likely to be “disruptive and viewed with suspicion”.

An interesting aspect of this method is that the questions always ask for gist-type information (e.g. Which has the lower altitude, TWA799 or AAL957?) and not for unique data on a single aircraft. The logic behind gist-type questions is the assumption that controllers do not memorise data on aircraft in isolation (see Section 6). Most of the time they do not need to commit this data to memory because the information is available either on the radarscope or on the strips. This assumption is in agreement with the studies made in France on Controllers’ Mental Representation (see Section 7).

One limitation of the SPAM method is that the questions and answers are verbal: addressing spatial representation of traffic in an airspace is more difficult verbally than manually i.e. via drawing techniques (e.g. the map in SAGAT).

Another concern might be that SPAM measures are dependent on workload and spare capacity. The fact that controllers have access to the information and can refer to it to answer could be interpreted as an indicator of the spare workload capacity more than a S.A. indicator. This argument loses strength when remembering the assumption of S.A. on which SPAM is based: S.A. may simply involve the human knowing where in the environment to find the information when needed.
9.2. Ratings techniques

9.2.1. Self rating techniques

The main advantages of these techniques are their ease of use and low cost. An important problem is that people are not always aware of what they don’t know! Moreover, sometimes, in the case of experts, people don’t know what they do know: i.e. experts are not always aware of which data they do take into account. These measurement techniques are highly subjective and suffer from the possible influence of perceived performance and/or expected performance.

Endsley (1995 b) states “Self rating of S.A. most likely conveys a measure of subject’s confidence level regarding that S.A.- i.e. how comfortable they feel about their S.A.”

9.2.2. SART (Taylor 1990)

“SART was derived from the following working definition of S.A. “S.A. is the knowledge, cognition and anticipation of events factors and variables affecting the safe, expedient and effective conduct of the mission”” (Taylor et al. 1995a). SART allows operators to rate a system design, via bipolar scales, the degree (7 degree scales) of perception experienced:

- The amount of demand on attentional resources (D)
- Instability of the Situation i.e. likeliness to change suddenly
- Complexity of the Situation i.e. degree of complication
- Variability of the Situation i.e. number of variables and factors changing
- Supply of attentional resources (perceived workload) (S)
- Arousal i.e. degree of alertness or readiness for action
- Concentration of attention i.e. degree to which thoughts are brought to bear
- Division of attention i.e. distribution, spread of focus
- Spare mental capacity i.e. mental ability available for new variables
- Understanding of the situation provided (U)
- Information quantity i.e. amount of knowledge received and understood3
- Information quality i.e. accuracy and value of knowledge communicated
- Familiarity with the situation i.e. degree of prior experience and knowledge

These scales are then combined to provide an overall S.A. score for a given system:

Formula: S.A. (calculated) = Understanding – (Demand – Supply)

SART for pilots has a total of 14 components (3 global ratings of the basic dimension D, S & U + ratings of the 10 elements composing the dimension (bullets) + 1 S.A. simple rating: “How good is your awareness of the situation?”) which were determined to be relevant to S.A. through analysis with pilots.

It appears that the same dimensions are used for assessing ATCOs’ S.A. This is possible because of the non-relation between the dimension and concrete / specific aspects of task performed.

3 No questions are asked on information received but not understood and overloading!
SART can be proposed in different scale lengths: 14 scales corresponding to the 14 components described above, 10 scales corresponding to the 10 elements composing the dimensions, or 3 scales when reduced to the 3 basic dimensions.

Discussion

In addition to the generic comments that can be made to Self-Rating techniques (see under) it is to be noted that SART does not address the criteria/elements behind the scales and scores:
- We do not know which data was part of “the received and understood information”.
- We do not know in what aspect(s) the new situation was familiar to the subject.

This method might be interesting for comparison but does not provide high value information for first steps of design. As discussed above, bipolar scales are not really explanatory and not concrete.

SART is the most widely known Self-Rating Technique in the domain of S.A. measurements.

9.2.3. CC SART (Taylor 1995b)

By the same author, CC SART is built on the same principle. It is a set of rating scales intended to measure the system Cognitive Compatibility (CC).

Cognitive compatibility is defined by the author as “the facilitation of goal achievement through the display of information in a manner which is consistent with internal processes and knowledge, in the widest sense, including sensation, thinking conceiving and reasoning” or, more simply “Cognitive Compatibility refers to ease of perceiving, thinking and doing, in line with past experience, training and expectations”.

Like SART, the scales correspond to a set of 3 main dimensions and the 10 elements related to these main dimensions.

CC SART dimensions
Level of processing: degree to which the situation involves automatic processing or analytic and abstract processing.
- Naturalness
- Automaticity
- Association
- Intuitiveness
Ease of reasoning: degree to which the situation is confusing and contradictory or straightforward and understandable
- Straightforward
- Confusability
- Understandability
- Contradiction
Activation of knowledge: degree to which the situation is strange and unusual or is recognisable and familiar.
- Recognisability
- Familiarity

According to the experimental context (and again in the same way as SART) CC SART can be presented in 3 different forms:
- The 13-D version that comprises all the basic and main dimensions in a single set of rating scales.
- The 10-D version that comprises only the basic dimensions.
The 3-D version using only the main dimensions. The diagnostic power is reduced, compared with 13D and 10 D but Taylor proposes this form as the best candidate for collecting repeated measures during continuous activity.

CC SART is proposed as a complement to SART and aims at providing a more detailed measure of the understanding dimension involved in Situation Awareness.

The comments made concerning SART can be made for CC SART for the two methods follow the same principle and format (7 degree rating scales). Regarding the more abstract aspect of the dimensions in CC SART, it could be argued that it is more difficult to rate and therefore requires additional training of the subject before administration. This comment is counterbalanced by the advantage that examples of “every day life” are available in a computerised version for each of the scales.

9.2.4. S.A. SWORD (Vidulich and Hughes 1991 in Endsley 1996)

The authors have adapted the workload assessment technique SWORD to allow the ratings of the perceived S.A. provided by different displays. It is a comparative method. The subjects are asked to rate, on a nine–point scale, their preference amongst the tested displays in terms of perceived S.A. provided by each.

9.2.5. Peers or supervisor rating techniques

An independent observer is used to rate the quality of the subject’s S.A. The information gathered comes from observable behaviour including communications and verbalisation requested from the observer.

The major limitation is, as for all observation techniques, S.A. is a highly internal construct and, similar to the self-rating technique, this method can be influenced by the observer’s expectations and perceptions of performance.

The observer effect has been described by Hugh David (1998) “The controller will be aware that his actions are being assessed by another controller, and, may modify his behaviour, either by being over precise, or by trying to appear relaxed and “on top of the job”.”

Actions and verbalisations cannot be taken as a complete representation of the subject S.A.; information might be known and not mentioned, treatment of information may not be immediate according to the other task(s) performed at a given moment.

Requested verbalisations during the simulation run might be intrusive and artificially direct the attention of the subject to certain data that were, for the time being, only of importance for the observer. (There is also an important risk of interference with the verbal communication requested by the task!)

Last, but not least Hugh David underlines the risk that “the assessor, unless carefully briefed, may either start to assess the traffic rather than the controller, or may mentally impose his own “style of control as a standard”. This implies that “considerable effort must be invested in training and standardising the assessors.” The same comments can be made concerning observation techniques.
9.3. Performance based techniques

9.3.1. Performance based measurement


“Good S.A. is essential for safe and efficient performance of the controllers duties, and expert controllers palpably exhibit better S.A. than novice” (Rantanen & Butler), based on this statement, some methods propose to assess controllers’ S.A. via an evaluation of their performance.

Performances based methods have the advantage of generally being non-intrusive (data can be gathered during task performance without interruption) and rely on observable actions results or errors.

The delicate aspect of these methods is to find situations in which a clear and unambiguous response exists to establish whether the subject has “good” or “sufficient” S.A. It might be quite difficult to realise for ATCOs. The event (conflict), triggering the observable performance, needs careful investigation.

Whatever their domain of application, these methods pose the problem of the relevance of the performance indicator selected. When performance is assessed in its entirety, these methods suffer from a lack of diagnosis and sensitivity. When performance is assessed for specific subtasks (imbedded task measure) there is a risk of attracting the subject’s attention and thus reducing S.A. on another part of the task.

More critical is the question of the relation between S.A. and performance: Pew stated that “no criteria exist at this time that establish the level of S.A. required for successful performance”. Endsley (1995 b) asserts “…that S.A. can be seen as a factor that increases the probability of good performance but that it does not necessarily guarantee it, as other factors also come into effect (e.g.: decision making, workload, performance execution, system capacities, and S.A. of others in some cases)”. Halbert (1997) “S.A. is required as an impute to decision making, but must also be coupled with other factors to achieve safe and effective performance”. In some cases a low level of S.A. would not necessarily lead to a low performance if the subject is aware of his/her low awareness and can adapt his/her behaviour, for example choose a less elegant resolution in the absence of detailed information on the situation.

9.3.2. Implicit Performance Measures

(Sarter & Woods 1991; Sarter & Woods 1995)

The article of Sarter & Woods “Situation awareness : a critical but ill-defined phenomenon” published in 1991, seems to be, if one considers the number of times it is quoted by other authors in the field, THE reference when talking about Implicit Performance Measures.

Sarter & Woods argue that S.A. is a complex phenomenon “The need for perceiving, integrating, and retrieving competing information from a variety of sources is what makes it difficult to achieve and maintain situation awareness”.

They identify in this complexity a risk for the researcher to simply miss the phenomenon by either assessing only one little aspect of it or by the artificial aspect of simulations. “To give this phenomenon (S.A.) a chance to occur, it is necessary to stage complex dynamic situations that require resources comparable to high-fidelity full-mission simulation”. 
Implicit Measurement involves the design of experimental scenarios that include tasks and events that probe the subject’s S.A. and are operationally significant. Furthermore, these probes should provide cues that, if perceived, should lead to an observable change in behaviour.

In many cases (e.g. Durso et al., 1998) this technique has been realised by the introduction of error into an otherwise typical situation. The speed of detection and the accuracy of correction are then used to assess the subject’s S.A.

Other possible ways of testing are suggested by Sarter & Woods (1991):

“Effacing specific data from a display just prior to events where the pilot can be expected to pay attention to them and observing when and how the pilot realises that important data are missing;

Asking the pilot for previously displayed information by calling or addressing him in the role of an air traffic controller, a company official, or another crew member (rather than as the experimenter)

Having a confederate first officer discuss a problem with the pilot to find out about his current awareness of the situation”

Implicit Performance Measures promoted by Sarter & Woods present the same advantages but also the same limitations as the majority of Performance Measures when used to assess S.A. (see above)

9.3.3. **GIM Global Implicit Measurement technique**

(Brickman, Hettinger, Stautberg, Haas, Vidulich et al. 1998)

This is an example of a performance-based technique founded on a detailed task analysis, task segmentation. The task analysis is used to create a highly detailed set of rules similar in nature to rules encountered in an operational context. Each of the “rules is treated as an individual implicit probe and assessed at the frame rate of the simulation”. In addition, the implicit probes can be weighted in order to yield a more realistic metric of S.A. based upon the relative importance of each probe as judged by subject matter experts.

Example: the rules of engagement specify a radar mode for each mission segment. If the pilot configures the radar correctly for that portion of the mission, the resulting score on the implicit metric would reflect adequate S.A. If the pilot sets the radar to any other mode, the score on that item would reflect inadequate S.A.

This method has been conceived for assessment of crewmembers during an air-to-air combat mission. There is a question of the adaptability of this method to ATC? Do such well-defined rules exist in ATC? Probably not, there is seldom “just one correct answer” to a problem in operational ATC. As already remarked there are far less observable behaviours in the case of controllers.

However, an interesting area for further Human Factors research in the domain of ATC studies is the GIM approach to (and methodology underlying) the weighting of the detailed task analysis by subject matter experts.
9.4. Others

9.4.1. Cognitive interviews

These techniques require a simple technical organisation and have the advantage of being non-intrusive. "In general, traditional queries assume the contents of the situation model and are used to assess its completeness and accuracy. Structured interview questions are more open and intended to reveal the contents of the situation model rather than assess it." Cooke, Stout & Salas (1997)

However, this technique poses the problem of the limitation of recall, which does not imply that the information was not taken into account during task performance. This problem can be reduced by the use of video recording re-play "auto confrontation".

Another risk is the phenomenon of reconstruction according to what usually happens or what the subject thinks (most of the time unconsciously) is expected from him/her : what will be "status–enhancing" : “.. Sometimes..., they may give responses that are either : what they think the group as a whole think or what they think the observer wants to hear” Hugh David (1998).

A further limitation underlined by the same author : “Controllers, like any other subjects, are extremely sensitive to minor, nearly subliminal signals from the interviewer.”

9.4.2. Observations

The opinion of many Human Factors specialists is that observation techniques should be considered as a complement to and a first step before the application of another method of investigation. S.A. is an internal psychological construct and process, observed behaviour can provide some limited insights. This latter statement is especially true for ATCOs where physical behaviour available for observation is even more limited than that of pilots.

The “cost” of observation is often underestimated, it is extremely labour intensive both when gathering the information and during analysis.

The quality of the observer is very important: domain knowledge helps focus on task relevant observations. The cues on controller performance may not be sufficiently salient for an observer not familiar with ATC.

On the other hand “The expertise also makes it difficult to see some subtle actions meaningful enough to record, even though such small subtle occurrences may be important” C. A. Halverson (1994).

Finally, limitations of human observation capabilities must not be forgotten especially in the case of the observation of simultaneous events.

Nevertheless, “Behavioural Checklists” have been used to record observed S.A. relevant behaviour. (Shrestha, Stout 1995) (The behavioural checklist was established for crew members)
9.4.3. Enard (1968)

Enard applied an interesting approach to controller’s mental representation of airspace in 1968. She used video recordings of ATCOs drawing their representation of the sector map. This allowed capture of the prioritisation of the elements and also their groupings (not only geographical /physical).
10. CONSOLIDATION

ATM Human Resources Unit at EUROCONTROL Headquarters definition of S.A.: “The perception of the elements in the environment within a volume of time and space, comprehension of their meaning and the projection of their status in the near future. This also means the continuous extraction of environmental information and the 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. Situational Awareness is established by a continuous comparison between anticipation (predicted state of the system) and environmental input (actual state of the system)”

To this definition, directly inspired from Endsley and from Dominguez, we think that it is important to add following S.A. characteristics:

- S.A. is transient;
- S.A. is different, in a same situation, for different persons;
- The mental representation issued from S.A. is not an exact reflection of reality, rather a distortion according to the goals of the subject and also to his/her experience;
- S.A. is not limited to information directly related to the traffic, factors such as personal factors, perceived performance levels of colleagues must be taken into account.

Far less has been offered in terms of a definition for Team S.A.

Methods to measure (assess) S.A. can be grouped in three categories:

10.1. Query techniques (sometimes called knowledge-based techniques)

With these techniques the subject is questioned during the experimental run, with interruption of the exercise (SAGAT) or without (SPAM). The measure is the accuracy of the response and/or the time lapse between the question and the answer. Two limitations can be identified in the use of SAGAT as it is proposed now:

1. the “natural” flow of the task is disrupted, and
2. information is requested and used for calculation of result without any consideration given to the different levels of importance of aircraft.

SPAM is based on the assumption that, according to the increasing complexity of the technical system, “good SA” is maybe more concerned with being able to find the information when needed than in memorising a great amount of information.

10.2. Rating techniques

The subject (SART, CCSART) or a peer rates S.A. according to different dimensions usually presented in the format of scales. The limitations of these techniques are that they are highly subjective and too general.
Performance based techniques (as opposed to knowledge-based techniques).

The rationale behind these techniques is that good S.A. is needed to reach a good level of performance. Global performance or performance in part task is then measured as an indicator of S.A. These methods have been criticised for if S.A. is effectively a factor furthering success; performance is also based on other phenomenon.

Negative impacts of automation on S.A. have been widely described. Automation is associated with an increase in the complexity of the technical system and of its interface. The change of the nature of workload i.e. workload involving physical activity changing to workload involving cognitive and perceptual activity. The risk involved is to impair S.A. by overloading the Working Memory. This point loses significance in the case of Air Traffic Control which is already a highly cognitive task.

Levels of automation are presented as a possible solution to introduce S.A. while minimising its drawbacks.

In this perspective we find that it is essential not to consider the task of ATC in its entirety but rather to break it down into several dimensions (cf. Wickens et al. 1998). Thus different levels of automation can exist for different aspects of the task.

Several lists of S.A. requirements for Air Traffic Controllers have been proposed. It is interesting to note that many (including Endsley’s and Rodgers’s) contain only data directly related to the traffic situation. If we consider that S.A. is the basis of decision making and that controllers process information as described in the IMPACT Mental Model, we believe that these lists must include a wider scope of information and include personal factors, information on colleagues etc. Bert Ruitenberg (see Annexe B) proposes an example of this type of list.

Finally it is important to remember that the importance of each element will vary according to the evolution of the situation.

It has also been stated that more important than the elements themselves, it is their interrelation and their dynamic change that are critical to assess the complexity and richness of S.A.

Errors can be interpreted within the framework of Endsley’s three-level S.A. model. Level 1 S.A. errors correspond to failure to correctly perceive the situation; Level 2 S.A. errors correspond to failure in integration, interpretation of the situation and Level 3 errors correspond to failure to accurately project the situation.

Durso et al. (1997) reported that classifying errors according to these categories is a difficult exercise for it appears to be difficult to clearly distinguish between comprehension and prediction.

Finally, awareness of error appears, according to several analyses based on real incident reports, to have an influence on the severity of the error.

Controller Awareness is associated with less severe errors. In fact, the difference of severity is related to the different type of errors made by aware and unaware controllers. Aware controllers have a tendency to make ‘judgement’ errors while unaware controllers make more ‘memory’ and ‘perceptual’ errors.
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Annexe A: Lists of Elements, “S.A. requirements” for ATCOs

Elements identified by the NATS HUM team via Picture Interview:

- radar map;
- strips;
- relative positions of aircraft;
- looking ahead;
- teamworking;
- weather;
- procedures;
- callsign information;
- flight level;
- speed;
- space between time histories;
- route;
- tone of voice of pilot;
- performance;
- airline company
Elements identified in the model of Bert Ruitenbergh:

- Personal factors
  - Physical comfort
  - Stress
  - Fatigue
- Weather
  - Current forecast
  - Special weather event
- Airport infrastructure
  - Available runways
  - Work in progress
- Colleagues
  - Strengths/weaknesses
  - Performance level
  - Social gradient
  - Training in progress
- Traffic
- Operators & Pilots
  - Pilots R/T level
- Performance level of various operators
- Environment
- Navigational aids
  - Availability
  - Performance level
- Aircraft performance
- Equipment
  - Availability
  - Performance level
  - Reliability
  - Degradations
- Adjacent centres
- Capacity
- Performance level
- Limitations
S.A. requirement Elements identified by Endsley

LEVEL 1 S.A.

Aircraft
- aircraft ID, CID, beacon code
- current route (position, heading, aircraft turn rate, altitude, climb/descent rate, ground speed)
- current flight plan (destination, filed plan)
- aircraft capabilities (turn rate, climb/descent rate, cruising speed, max/min speed)
- equipment on board
- aircraft type fuel/loading
- aircraft type
- activity (enroute, arriving, departing, handed off, pointed out)
- level of control (IF VFR, flight following, VFR on top, uncontrolled object)
- aircraft contact established
- aircraft descent established
- communications (present/ frequency)
- responsible controller
- aircraft priority special conditions, equipment malfunctions emergencies
- pilot capability/state/ intentions
- altimeter setting

Emergencies
- type of emergency
- time on fuel remaining
- souls on board

Requests
- pilot/ controller requests
- reason for request

Clearances
- assignment given
- received by correct aircraft
- read back correct/ complete
- pilot acceptance of clearance
- flight progress strip current

Sector
- special airspace status
- equipment functioning
- restrictions in effect
- changes to standard procedures

Special operation
- type of special operation
- time begin/ terminate operations
- projected duration
- area and altitude affected

ATC Equipment Malfunctions
- equipment affected
- alternate equipment available
- equipment position/range
- aircraft in outage area

Airports
- operational status
- restrictions in effect
- direction of departures
- current aircraft arrival rate
- arrival requirements
- active runways
- approach sector saturation
- aircraft in holding (time, number, direction, leg length)

Weather
- area affected
- altitudes affected
- conditions (snow, icing, fog, hail, rain, turbulence, overhangs)
- temperatures
- visibility
- winds IFR/VFR conditions
- Airport conditions
LEVEL 2 S.A.

Conformance
- amount of deviation (altitude, airspeed, route)
- time until aircraft reaches assigned altitude, speed, route/heading

Current Separation
- amount of separation between aircraft/objects/ airspace along route
- deviation between separation and prescribed limits
- number/timing aircraft on route
- altitudes available

Timing
- projected time in airspace
- projected time till clear airspace
- time until aircraft landing expected
- time/distance aircraft to airport
- time/distance till visual contact
- order/sequencing of aircraft

Deviations
- deviation aircraft/ landing requests
- deviation aircraft/flightplan
- deviation aircraft/pilot requests

Other Sector/Airspace
- radio frequency
- aircraft duration/reason for use

Significance
- impact of requests/ clearances on:
  - aircraft separation/ safety
  - own/other sector workload
- impact of weather on:
  - aircraft safety/ flight comfort
  - own/other sector workload
  - aircraft flow/routing(airport arrival rates, flow rates, holding requirements, aircraft route, and separation procedures)
- altitudes available
- traffic advisories
- impact special operations on sector operations/procedures
- location of nearest capable airport for aircraft type/ emergency
- impact of malfunction on:
  - routing,
  - communications,
  - flow control,
  - aircraft,
  - co-ordination procedures,
  - other sectors own workload
- impact no. of aircraft on workload

- sector demand vs. own capabilities

Confidence level / Accuracy of info
- aircraft ID, position, altitude, airspeed, heading
- weather
- altimeter setting

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LEVEL 3 S.A.

Projected Aircraft Route
- (Current)
- position, flight plan, destination, heading, route, altitude, climb/ descent rate, airspeed, winds,
groundspeed, intentions, assignments

Projected Aircraft Route
(Potential)
- projected position x at time t
- potential assignments

Projected Separation
- amount of separation along route (aircraft/ objects/airspace/ground)
- deviation between separation and prescribed limits
- relative projected aircraft routes
- relative timing along route

Predicted Changes in Weather
- direction/speed of movement
- increasing/decreasing in intensity

Impact of Potential Route Changes
- type of change required
- time and distance till turn aircraft
- amount of turn /new heading altitude route change required
- aircraft ability to make change
- projected no. of changes necessary
- increase/decrease length of route
- cost/benefit of new clearance
- impact of proposed change on:
  - aircraft separation
  - arrival requirements
  - traffic flow
  - number of potential conflict
  - flow requirements (spacing, timing)
  - aircraft fuel and comfort
Annexe B: Examples of SAGAT queries

From: Porter A W, February 1996, “Investigating the effects of Automation on Situation Awareness”, (PHARE GHMI Task 1.2.2) DRA/LS (LSC4)/CHCI/CD299/1.0
Question 1
Enter the location of all aircraft on the picture below. Use a “+” to represent aircraft under your control, a “O” to represent other aircraft in the sector and “□” to represent aircraft which will be under your control in the next 2 minutes. Number the aircraft consecutively, the numbers will be used to uniquely identify the aircraft in the following questions.
**Question 2**
For each of the aircraft in question 1 enter the aircraft callsign in the table below.

<table>
<thead>
<tr>
<th>Aircraft Number</th>
<th>Aircraft Callsign</th>
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</tbody>
</table>
Question 3
For each of the aircraft in question 1 enter the aircraft’s altitude in feet ÷ 100 in the table below. e.g. 22000 □ 220

Question 4
For each of the aircraft in question 1 enter the aircraft ground speed, in knots, in the table below.

Question 5
For each of the aircraft in question 1 enter the aircraft heading, in degrees, in the table below.

Question 6
For each of the aircraft in question 1 enter the aircraft’s flight path change in the table below by checking one box in the “Altitude” column and one box in the “Turn” column. “↑” indicates ascending, “↓” indicates descending, “L” indicates level, “→” indicates right turn, “←” indicates left turn and “S” indicates straight.

<table>
<thead>
<tr>
<th>Aircraft Number</th>
<th>Altitude</th>
<th>Turn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□ ↑</td>
<td>□ ↓</td>
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<tr>
<td></td>
<td>□ ↑</td>
<td>□ L</td>
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<tr>
<td></td>
<td>□ →</td>
<td>□ ←</td>
</tr>
<tr>
<td></td>
<td>□ S</td>
<td></td>
</tr>
</tbody>
</table>

Question 7
For each of the aircraft in question 1 enter the aircraft type in the table below. e.g. B 747 for Boeing 747

Question 8
Which pairs of aircraft have lost or will lose separation if they stay on their current (assigned) courses?
If none of the aircraft have or will lose separation, check (□) the “None” box.
None □

Question 9
Which aircraft have been issued assignments that have not been completed?
If none of the aircraft have, check (□) the “None” box.
None □

same kind of table as for question 2
**Question 10** (This question relates to question 9. If you answered “None” Please go on to question 12)
Did each of the aircraft listed in question 9 receive its assignment correctly? Enter Yes or No.

**Question 11** (This question relates to question 9. If you answered “None” Please go on to question 12)
Which aircraft listed in question 9, are currently conforming to their assignments? Enter Yes or No.

**Question 12**
Which aircraft will be handed off to another sector / facility in the next 2 minutes?
If none of the aircraft will, check (☑) the “None” box.

**Question 13**
Enter any aircraft that are experiencing a malfunction or emergency that is effecting operations.
If none of the aircraft are, check (☑) the “None” box.

**Question 14**
Enter all aircraft that are NOT currently in communication with you.
If all of the aircraft are, check (☑) the “None” box.

**Question 15**
Enter all the aircraft that are NOT conforming to their flight plan.
If all of the aircraft are conforming to their flight plan, check (☑) the “None” box.
Annexe C: Examples of SPAM queries

As used in experimentation at FAA Technical Center, Human Factors Laboratory, Atlantic City, NJ, USA.

15:30
Will US Air 1650 and Continental 707 be in conflict if no further action is taken?

21:00
Which will leave the airspace first, Delta 1481 or US Air 2934?

28:00
Are there any speed conflicts on the J74 airway?

32:00
Which is at a faster groundspeed, US Air 992 or Spirit Wings 2249?

41:00
Which is at a higher altitude, US Air 153 or Delta 1676?

43:00
Which is travelling at slower groundspeed, US Air 124 or Continental 1962?

Which will reach their final altitude first, Trans World 1432 or Delta 1586?