Situational Awareness

and

Interactive System Safety Analysis

A Thesis Submitted in Partial Fulfilment of the Requirements

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Abstract

This research is concerned with the analysis of safety in complex, interactive systems which characteristically support dynamic processes involving large numbers of hardware, software and human elements that interact in many different ways. Interactive systems present unique hazards and problems and human error is a major contributing factor, or even the direct cause, of accidents or incidents. Paradoxically, many system developers concentrate their efforts upon technical issues often neglecting the human factors. Traditional reliability engineering techniques do not fit well with human factors issues and this dissertation argues that human error is best examined from a cognitive perspective. One phenomenon which has emerged as a useful framework for evaluating human cognition in context is situational awareness. In complex systems, an operator's situational awareness can be significantly influenced by the design of the system interactions. This dissertation undertakes a critical review of the literature relating to situational awareness and a Situated Cognition perspective is synthesised from the dominant views relating to this phenomenon. This Situated Cognition perspective encapsulates the equal importance of the process of acquiring situational awareness and the resulting state of awareness. The dissertation also highlights the limitations associated with the adoption of reductionist approaches for studies of human cognition. A number of different research approaches have been proposed which consider the situated nature of human cognition and Activity Theory is chosen for this research as an appropriate research method for capturing the richness of human cognition in context. From this theoretical basis, an Interactive System Safety Analysis Method is proposed which integrates separate techniques for the evaluation of situational awareness through analyses of both situated interactions and the resulting state of situational awareness in context. Interactive System Safety Analysis Method is developed and modified during an initial Pilot Study and a main field study of the United Kingdom Air Defence system. An appraisal of Interactive System Safety Analysis Method is undertaken and a generic version of the method is developed for the general analysis of complex, interactive systems in context. The research concludes that situational awareness is a critical system attribute and that Interactive System Safety Analysis Method can inform the system development process and thus mitigate against the hazards inherent in complex, interactive systems.

Keywords: Safety, Situational Awareness, Interaction, Activity Theory.

Publications and Other Material

The research contained in this thesis was carried out between September 1997 and February 2000. This thesis contains the following material that has already been presented as published papers, submitted papers, conference papers and technical reports[1]:

Published Papers

Macredie R D and Sandom C (1999), *IT-Enabled Change: Evaluating an Improvisational Perspective*, European Journal of Information Systems, 8(4), 247-259, December 1999.

Sandom C and Macredie R D (1998), *Software Hazards and Safety-Critical Information Systems*, SCSC Newsletter, 7(3), 11-13, May 1998.

Sandom C and Macredie R D (1998), *Software Hazards and Safety-Critical Information Systems*, http://forum.iee.org.uk/forum/library/view.cgi/1998_09/sandom/sandom.htm, IEE Computer Forum, 25 September 1998.

Submitted Papers

Sandom C and Macredie R D (1999), *A Situational Awareness Process Model for System Safety Analysis*, submitted to Reliability Engineering and System Safety, October 1999.

Sandom C and Macredie R D (1999), *An Activity Theory Approach to Situated Interaction Hazard Analysis*, submitted to International Journal of Human-Computer Studies, December 1999.

Conference Papers

Sandom C (1999), *Situational 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 (2000), *Operator Situational Awareness and System Safety*, IEE Systems Dependency on Humans Seminar, Publication No. 00/20, IEE, Savoy Place, London, 16 February 2000.

Technical Reports

Sandom C (1999), *UCMP Human Computer Interface Safety Study Report*, 11/18G(BP)/1480/102/3/1/ASSU, RAF Bentley Priory, 16 November 1999.

Sandom C (1998), *UCMP Human Computer Interface Evaluation Survey*, SDC/1480/102/3/1/UST, RAF Bentley Priory, 20 March 1998.

[1] The author of this dissertation was the principal contributor to any of the dual named papers.

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Glossary of Terms

ACMI	Air Combat Manoeuvring Instrumentation
AD	Air Defence
ALARP	As Low As Reasonably Practicable
AT	Activity Theory
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
BCU	Bird Control Unit
C2	Command and Control
CAA	Civil Aviation Authority
CAOC	Combined Air Operation Centre
COTS	Commercial Off The Shelf
CRC	Control and Reporting Centre
CRP	Control and Reporting Post
DCS	Data Communications System
DDN	Digital Data Network
DFTS	Defence Fixed Telecommunication System
DHS	Data Handling System
DLB	Data Link Buffer
DVCS	Display and Voice Communication System
EA	Exercise Administrator
EC	Exercise Controller
EDDIE	Enhanced Data Display for the ICCS Environment
FA	Fighter Allocator
FPDS	Flight Plan Dissemination System
G/A	Ground-to-Air
G/G	Ground-to-Ground
HAZOP	Hazard and Operability Study
HCI	Human Computer Interaction
HRA	Human Reliability Analysis
HSE	Health and Safety Executive
IADS	Iceland Air Defence System
ICCS	Integrated Command and Control System
IDO	IDentification Officer
IEC	International Electrotechnical Commission
IGACS	Integrated Ground-to-Air Communications System
ISA	Independent Safety Advisor
ISSAM	Interactive System Safety Analysis Method
ITD	Interactive Tote Display
MC	Master Controller
MoD	Ministry of Defence
NADGE	NATO Air Defence Ground Environment
NATS	National Air Traffic Services

ODS	Operator Display System
PHA	Preliminary Hazard Analysis
PHI	Preliminary Hazard Identification
RAP	Recognised Air Picture
RCSS	Radio Control Sub-system
RDC	Resource Data Catalogue
RAF	Royal Air Force
RP	Reporting Post
RRP	Remote Reporting Post
SA	Situational Awareness
SAGAT	Situational Awareness Global Assessment Technique
SAPAT	Situational Awareness Process Analysis Technique
SART	Situation Awareness Rating Technique
SDC	System Development Centre
SFK	Special Function Keys
SHA	Safety & Hazard Analysis
SIF	System Identification Function
SMF	System Maintenance Facility
SoFC	School of Fighter Control
SRAP	Surface and Recognized Air Picture
SRK	Skill-Rule-Knowledge
SSR	Secondary Surveillance Radar
STARTS	Software Tools for Application to large Real-Time Systems
TACRO	TACtical Radar Operator
TD	Trace Driver
TPO	Track Production Officer
TTD	Tabular Tote Display
UC	Universal Console
UCMP	UKADGE Capability Maintenance Programme
UKADGE	United Kingdom Air Defence Ground Environment
UKADR	UK Air Defence Region
UKCAOC	UK Combined Air Operations Centre
USSS	UKADGE System Safety Study
VCS	Voice Communications System
WC	Weapons Controller
WCA	Weapons Controller Assistant

Chapter 1

INTRODUCTION

1.1 PROBLEM DEFINITION

The design of a modern interactive system is a complex affair. The rapid pace of technological change can often result in the use of unproven and unpredictable technology as systems developers attempt to implement technology-driven design solutions – failures can be dramatic and costly (Benyon-Davies 1995; Eason 1989). To compound the problems associated with functional complexity, interactive systems are often integrated into complicated social and organisational environments (Macredie *et al.*1998). Complex, interactive systems such as these are the central focus of this dissertation and they can be defined as systems that support dynamic processes involving large numbers of hardware, software and human elements that interact in many different ways (Perrow 1984).

Complex, interactive systems are often required to assist human operators with intricate tasks such as, for example, the conflict detection and resolution systems that assist Air Traffic Controllers with critical decision making tasks in modern Air Traffic Management Systems (Hopkin 1995). Some complex, interactive systems even carry out safety-related tasks themselves. For example, computer systems are used to directly control the nuclear fission process in nuclear reactors while human operators merely monitor the system for problems (Leveson 1996). As well as the complexity of modern technology and organisations, humans are also inherently complex and human factors relating to the physical and cognitive capabilities and limitations of the operator must also be addressed during the development of any complex, interactive system (Hopkin 1995).

The technical, human and social complexity involved in the development of a modern interactive system presents a number of difficulties for the systems developer. Many different system development techniques and methods have been evolved to support the management of complexity in the design process (for example see Avison and Fitzgerald 1995). However, the rate of technological change has often been faster than any improvements in the design of tools and techniques and the hazards associated with system complexity generally remain during development. These problems can manifest themselves when system operators initiate unintended sequences of events with lethal consequences. This was clearly the case when the crew of the USS Vincennes incorrectly interpreted the information presented by their system and a decision was taken to shoot down a commercial airliner killing 290 passengers (Greatorex and Buck 1995).

While this may be a extreme example taken from a military context, interactive systems are increasingly being integrated into social contexts where their correct design and operation is essential in order to ensure the safety of the general public and the environment. Systems such as these are often referred to as safety-related systems. Many safety-related systems are being developed with the potential for increasingly catastrophic consequences from a single accident and system safety is rapidly becoming a major social concern (Storey 1996; Leveson 1995). Safety engineering has recently emerged as a new field in order to address issues such as these by applying management techniques and engineering principles to the development of safety-related systems (Redmill 1997). However, safety engineering focuses almost entirely on the technical aspects of the system and the important human and organisational factors are generally neglected or even ignored. Yet, there is an increasing awareness that the design of a safety-related system must address the culture of the social groups that use them (Rochlin 1997; Westrum 1997). For example, social and cultural issues were dominant factors in the failure of the London Ambulance Service Computer-Aided Dispatch system which may have contributed to between 20-30 deaths as a result (Benyon-Davies 1995).

Safety is an important factor in the development of interactive information systems which are predominantly concerned with the effective design, delivery, use and impact of information technology in organisations and society (Avison and Fitzgerald 1995). However, the power of information technology has increased complexity as it has enabled the creation of entirely new forms of socio-technical systems whose possibilities and risks are often not fully understood (Rochlin 1997). Clearly, the development, implementation and operation of safety-related interactive systems are important issues for the information systems researcher.

1.2 SCOPE AND GENERAL DEFINITIONS

1.2.1 Human Factors and System Safety

Studies of safety-related systems have in the past considered safety predominantly from a technical perspective. Such studies have typically been limited to addressing hazards that could arise through hardware failures alone, yet human factors issues are becoming increasingly important in the design and evaluation of safety-related systems. This change in perspective has revealed a complex set of 'human' problems that are extremely challenging. The hazards associated with human failures are very different from those 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 of users. The identification of interaction hazards arising during system use may help designers to improve the system interface and interactions such that the associated risks are mitigated or even eliminated. However, in order to study these interaction hazards, appropriate research constructs are required to help designers to understand the user's cognition during system use.

This research will introduce a safety perspective into the study of human-computer interactions. Although the term human-computer interaction was adopted in the mid-1980s there are still no currently agreed definitions in the field (ACM SIGCHI 1992). As in any new research field, the terminology used in safety engineering is also often used inconsistently; indeed this confusion is often compounded by the use of the same terms, but with different definitions (Storey 1996). The aim of the reminder of this section is to outline the scope of this research and to establish broad definitions for some of the key topics examined throughout this dissertation. A more detailed examination of the core concepts addressed by this research are presented in Chapters 2 and 3.

1.2.2 Human-Computer Interaction

This research will focus on a number of important issues concerned with the analysis of system safety. Specifically, the research will examine the field of Human Computer Interaction (HCI) and the analysis and design of human-computer interactions. HCI is an important area of information systems development and the design of the human-computer interface can have a profound effect on the safety of any system (Storrs 1997; Leveson 1995).

HCI is primarily concerned with the study of people and computer technology and the ways that these influence each other. The field of HCI is influenced by several disciplines, in particular computer science, psychology, cognitive science and sociology. This dissertation will focus primarily on human-computer interactions from a computer science perspective.

The expression *human-computer interaction* is often taken to mean a single user interacting with a computer-based system. However, human-computer interactions do not occur in isolation from their environment and users of safety-related systems operate in a wider social and organisational context (Winograd and Flores 1993; Suchman 1987). It is, therefore, helpful to analyse the meaning of each component of the term *human-computer interaction* in order to arrive at a broader definition of the phrase that will be used throughout this dissertation:

- Human. In contrast to the traditional view of HCI, the human component of an interaction should be taken to mean either an individual system user or a group of system users collaborating within an organization to achieve a common goal. Expressed simply, the human user is whoever is trying to achieve a task using the computer system in question.

- Computer. The computer component of a human-computer interaction should be interpreted as any computer-based system ranging from a relatively simple desktop computer system to a complex, real-time embedded computer system. Computer systems such as these may also contain non-computerised components including other people and organisational procedures.

- Interaction. It is important to clarify the distinction between an interaction and an interface. An interaction is the *process* of communication between a user and a system; however, this communication is normally affected through the system interface. An interaction should be interpreted as any communication between the user and computer within a social and organisational context that affects both the human and the computer components of the system.

Quantitative measures of performance are present in almost every field of design when there is a demand for progressive improvement, however they are noticeably absent in the design of human-computer interaction (Newman 1997). System requirements specification documents often include the unhelpful phrase, "*The interface must be at least as good as the current* *interface"*. As a result, it is often difficult to provide a convincing argument that interactive systems are safe. This is a major problem for safety-related system developers as a safety case must be written with a convincing argument and supporting evidence that the new system is safe enough to satisfy a regulatory authority. This dissertation will address this issue by providing system developers with a method of evaluating human-computer interactions and helping to generate the evidence necessary to provide safety assurance.

1.2.3 Context and Situated Cognition

Studies of the interaction between computer-based systems and their human operators often focus on human-computer interactions without considering the emergent properties of human-computer systems in use. As systems become more complex, and operating environments more dynamic, the role of the operator has typically changed from providing manual to cognitive control. The nature of the interaction in these modern systems has changed from physical work with the body to cognitive work with the mind. This perspective is characterised by the 'glass cockpit' design of many modern aircraft where the pilot is often removed from direct manual interaction to assume a system management role. An understanding of human cognition in context is thus central to the design of human-machine systems and this is particularly pertinent in safety-related systems when the elimination of hazards is a principal concern.

The dominant cognitive paradigm in HCI research has been based on the human information processor (as characterised by the seminal work of Card *et al.* 1983). Although this model has been widely adopted there are a number of limitations associated with this reductionist paradigm for human cognition (see for example Nardi 1996; Hutchins 1995; Suchman 1987; Winograd and Flores 1986). A key limitation with this model is that it has neglected the importance of human cognition when interacting with computer systems situated in the real world (Landauer 1987). This brief discussion suggests that an understanding of cognition requires a 'situated' approach through careful consideration of the social and organisational aspects of HCI in context.

The social context of information systems is however often still ignored by system developers and the focus for HCI research often remains fixed on the individual (Nardi 1996a; Suchman 1987). Because the principle unit of analysis has typically been the individual, many of the early theories and methods of HCI have evolved either from a psychological or a cognitive science perspective (Dix *et al.* 1998; Hopkin 1995). However, the situated nature of information systems is now being acknowledged and systems theories and models are being adopted and adapted from the social sciences to address the context of system use (Yetton *et al.* 1994; Benjamin and Levinson 1993). This research aims to explore the nature of situated cognition and the hazards peculiar to the safety of interactive systems in the context of their use.

1.2.4 Situational Awareness and Situated Interactions

For complex systems situated in dynamic environments, an operator must 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. System operators are often presented with a myriad of information in different forms and they must use their training, skill and experience to build a representation of a situation involving past, present and potential future system states (Sarter and Woods 1991).

Situational awareness is one cognitive phenomenon that can be profoundly affected by the design of a human-computer interface; particularly when a system is situated in a dynamic environment (Hopkin 1995). Situational awareness is a complex concept and it is difficult to find an accepted definition of the term (Charness 1995; Hopkin 1995). A critical review of the literature relating to situational awareness is presented in Chapter 3 in order to provide the reader with a comprehensive understanding of this key concept for the remainder of this dissertation. Nevertheless, a broad definition that will be useful here is that situational awareness can be thought of as “having the bubble” (Roberts and Rousseau 1989, p.132). This expression is intended to convey the feeling that the ‘bubble’ (awareness) expands as more situational information is assimilated by an operator until a point when the bubble can burst and situational awareness is lost.

In many cases humans are no longer able to appreciate the true situation without the aid of complex, interactive systems. Interactive systems must therefore tell us more of what we need to know and they must do it more effectively and less ambiguously than before. Human operators working in dynamic environments must interact with systems in order to create and maintain situational awareness. The design of the system can thus have a profound effect on operator awareness and ultimately upon system safety. However, human cognition has its capabilities and limitations and a better understanding of critical cognitive phenomenon can be used to inform the design of human-computer interfaces (Gardiner and Christie 1987) and may provide interactions which help maintain the user's situational awareness.

The enhancement of situational awareness has become a major design goal for those developing operator interfaces for a wide variety of safety-related systems (Charness 1995). Rochlin (1997) even argues that, in complex technical systems, there may be a direct correlation between disrupting the situational awareness of the operator and controlling system risk. Simply stated, situational awareness must be created and maintained to enable safe system operation. Human cognition has inherent limitations which are generally dependent upon the cognitive capacity available for the assimilation of information and this is profoundly affected by the design of the system. Human-computer interactions should enable the user to create and maintain a safe level of situational awareness and the design of an interface and user interactions can therefore have a tremendous effect on the safety of the system (Rajan 1997).

This dissertation will argue that operator situational awareness is critical to system safety and that it can be used to help to understand human cognition in context. This research will investigate the affects of interactions on operator situational awareness in order to assess their effect on the safe design of interactive systems. Specifically, this research will examine how situational awareness can be affected by the human-computer interactions arising from the use of complex, interactive systems in dynamic environments.

1.3 RESEARCH AIM AND OBJECTIVES

This research project started with a vague notion that situational awareness is an important attribute for safety in complex, interactive systems yet many attempts to assess system safety in this area involved quantitative usability measures such as ease of system use or speed of interactions (Shackel 1991). The research was given added impetus through a brief survey of requirements specification documents relating to a number of MoD procurement projects undertaken to replace ageing defence systems. All these projects included specific requirements that mandated a need to provide safety assurance by demonstrating that new human-computer interfaces would be "at least as safe" as current those in current systems.

The problem that remained was how to objectively assure the safety of such a subjective thing as a human-computer interface. This research was primarily undertaken to provide an answer to this difficult question which is expressed as a research aim and the related enabling objectives in the remainder of this section.

1.3.1 Aim

The aim of this research is to undertake an analysis of situational awareness and to evaluate its relationship to complex, interactive system safety.

1.3.2 Objectives

The aim of this research will be achieved by fulfilling the following objectives:

- Carry out a critical literature review to determine what situational awareness is and how it can be analysed and evaluated in a systems context.
- Identify and develop a suitable research method to frame an analysis of situated interactions and situational awareness.
- Undertake a field-study of a complex, interactive system to analyse and evaluate situational awareness in context and to assess its contribution to system safety.
- Propose a general method for evaluating the safety of an interactive system in terms of its relative support for situational awareness.

The objectives of this research are summarised in Table 1.1:

Literature Survey	Research Theory and Method	Field Study	Data Analysis and Interpretation	System Safety Analysis Method
Critique literature and develop stance on Situational Awareness (SA) and appropriate evaluation techniques.	Select appropriate theory and develop method of SA data collection and evaluation.	Apply SA evaluation technique to collect data on the problem domain.	Apply research theory to interpret data to validate and/or modify evaluation technique.	Propose a general method for conducting interactive system safety analysis.

Table 1.1 - Research Objectives

1.3.3 Research Contribution

This research has been undertaken to facilitate the evaluation of situational awareness and safety in interactive systems and the findings are expected to have general applicability. It is also expected that this research will inform current HCI theory and thus improve upon current system design techniques, particularly those concerning safety-related interactions. It is anticipated that this dissertation will provide a contribution to academics and practitioners in two specific ways. Firstly, it is hoped that the dissertation will inform the design of safety-related system interaction design. Secondly, it is expected that the dissertation will also contribute to the academic community through an evaluation of an appropriate theoretical approach to the analysis of human-computer interactions in context.

1.4 DISSERTATION STRUCTURE

The remainder of this section provides an overview of the contents of each chapter within this dissertation:

- **Chapter 2 - Interactive System Safety Analysis.** This chapter sets the context of the research with an explanation of functional safety that will provide the basis of a common vocabulary used throughout the remainder of the dissertation. Specifically, the chapter addresses the topics of risk management and the typical hazards associated with interactive systems.

- **Chapter 3 - Evaluating Situational Awareness.** This chapter sets the context of the research through a critical review of the dominant theoretical perspectives relating to situational awareness and a Situated Cognition perspective is developed. This chapter then examines the validity of the different techniques available for analysing and evaluating situational awareness and a requirement for a model of the process of acquiring and maintaining situational awareness is identified.

- **Chapter 4 – An Activity-Based Safety Analysis Method.** This chapter examines an Activity Theory approach to the analysis of interactive system safety. A Situational Awareness Process Model is then proposed which is consistent with the principles of Activity Theory and the chapter develops a method for analysing situated interaction hazards. The chapter also discusses the selection and adaptation of an existing technique for evaluating the product of awareness acquired by a system operator. Finally, this chapter outlines an initial proposal for an Interactive System Safety Analysis Method based upon an integrated approach to the analysis of situational awareness in context.

- **Chapter 5 - Field Study Criteria and Expectations.** This chapter discusses the requirements for a suitable field study that enables the objectives of this research to be fulfilled. The chapter provides a general description of the organization and the specific information system chosen for this research project together with justification of their suitability. The chapter concludes with a discussion on the expectations of the field study and an outline of how the preconceptions of the researcher may affect the research findings.

- **<u>Chapter 6 - An Interactive System Safety Study</u>.** This chapter will outline the structure and conduct of a field study of a complex, interactive system. The chapter will begin with a description of a pilot study which was undertaken to confirm the field study expectations and to identify suitable interaction scenarios for the main system safety study. The chapter will then outline the main Interactive System Safety Study which aimed to evaluate SA and human-computer interaction hazards in context.

- **<u>Chapter 7 - Data Analysis and Initial Interpretation</u>.** This chapter explains how the proposed approach to interaction analysis was used to analyse the data collected during the field study. The chapter also presents the initial interpretations from an Interactive System Safety Study.

- **<u>Chapter 8 - Interactive Safety Analysis for Complex Systems</u>.** This chapter presents an appraisal of the application of the proposed Interactive System Safety Analysis Method to the Interactive System Safety Study. The chapter also examines the practical applications of the safety analysis method related to a system life cycle. Finally, the chapter draws upon the field study findings to present generalised guidelines for the prevention and repair of interaction hazards affecting situational awareness and system safety.

- **<u>Chapter 9 - Conclusions and Future Research Issues</u>.** This chapter integrates the theoretical conclusions of the literature review with the interpretations from the field study in order to demonstrate that the aim and objectives of this research have been fulfilled. The chapter also discusses the academic and practical contribution of this research as well as the limitations. The dissertation concludes with a discussion on future directions for research arising from the study.

1.5 SUMMARY

The technical, social and human complexity involved in the development of modern interactive systems presents a number of problems that are exacerbated when the failure of an interactive system has potentially lethal consequences. Safety-related systems are used in complex social contexts and the integrity of their design and operation is essential in order to ensure the safety of the public and the environment. Complex, interactive systems such as these are the central focus of this dissertation and they can be defined as systems that support dynamic processes involving a large number of hardware, software and human elements that interact in many different ways.

This research will focus on a number of important HCI issues concerned with the development of safety-related systems and a safety perspective will be introduced into the study of human-computer interactions. The term *human-computer interaction* should be taken here to mean any communication between the human and the computer components of the system, where the human element may be an individual or a group collaborating within a social or organisational context to achieve a common goal.

Complex, interactive system operators interact and operate using a remarkable cognitive process which requires the creation and maintenance of situational awareness. Developing an understanding of how the situational awareness of an operator can be affected by disruptions caused by the design of the system interactions is an important safety issue that will be examined in this dissertation.

The aim of this research is to undertake an analysis of situational awareness and to evaluate its relationship to complex, interactive system safety. This will be achieved with a review of the literature relating to situational awareness and through the development of an interactive system safety analysis method. The interactive system safety analysis method will be validated through a field study of a complex, interactive system. It is expected that this research will inform current HCI theory and contribute to the development of methods for the evaluation of situational awareness in complex, interactive systems, particularly those relating to interactions situated in safety-related contexts.

Chapter 2

INTERACTIVE SYSTEM SAFETY ANALYSIS

2.1 INTRODUCTION

The aim of this chapter is to provide an explanation of what safety means in the context of complex, interactive systems. This is done in order to provide the reader with an understanding of the concept of safety and the associated terminology that will be used throughout this dissertation. The chapter will provide a foundation and a common vocabulary for the detailed discussion of situational awareness and its relationship with interactive system safety which follows in Chapter 3.

The chapter will begin with an explanation of the risk-based approach to safety management which has been advocated by the UK Health and Safety Executive and consequently has been adopted by many regulated sectors of industry throughout the UK. The risk-based approach essentially recognises that there is no such thing as a risk-free system and therefore all system hazards must be identified and their associated risks quantified. This is particularly difficult for interactive systems as most hazard analysis techniques focus only on the technical aspects. A brief discussion is also provided to explain the importance of human factors and specifically how human error can contribute to the majority of interactive system hazards.

HCI has increasingly come to concern itself not just with the mechanism of the interface, but also with a range of related psychological and social issues concerning the context in which human-computer systems are used (see for example Nardi 1996; Hutchins 1995; Suchman 1987; Winograd and Flores 1986). This shift in perspective within the HCI community is explored in this chapter in order to highlight the scope of hazard analyses required for interactive systems used in dynamic, operational environments. Addressing the issue of system context requires appropriate methods for analysing interactive systems in use and this chapter will discuss the difficulties associated with analysing the source of situated human-computer interaction hazards. A detailed discussion of an appropriate research method for analysing interactions in context is given in Chapter 4.

Ultimately, system developers must convince regulatory authorities and operators that their systems are safe to operate and a safety case is often required to provide system safety assurance. This chapter will outline the general activities required during the system life-cycle to give the reader an appreciation of the difficulties of collecting appropriate data to provide safety assurance for interactive systems. The chapter will conclude by presenting an argument for addressing these difficulties by quantifying system safety in terms of the level of situational awareness acquired through interaction with the system.

2.2 SAFETY AND INTERACTIVE SYSTEMS

2.2.1 A Risk-Based Approach to Functional Safety

Advances in modern technology occur at an increasingly rapid rate along with the potential consequences of accidents from computer-based systems (Rochlin 1997; Leveson 1995). The concepts of functional safety and risk are therefore important topics for information system designers. Rochlin (1997) maintains that the power of information technology has enabled the creation of entirely new forms of socio-technical systems whose possibilities and risks are often not fully understood and safety is becoming an increasingly important concept in this area. Storey (1996) argues that modern system designers are becoming aware of the safety implications of the systems they develop; however there are still many dramatic and recent examples of accidents associated with computer-based systems that have resulted in multiple fatalities (see for example Leveson 1995).

The term ‘safety’ has many different connotations and it can be related to many different concepts such as Occupational Health and Safety, Road Safety or even Flight Safety. It is therefore important to make the distinction between these concepts and functional safety in order to appreciate what it is that safety-related system designers are trying to achieve. Storey (1996) maintains that functional safety is often confused with system reliability; however, even the most reliable system may not necessarily be safe to operate. For example, the cause of the Airbus A320 Strasbourg accident was attributed to the fact that the pilot inadvertently selected a descent rate that was too fast – the aircraft behaved reliably but it crashed into a mountain with fatal consequences (Storrs 1997).

Functional safety is a complex and difficult concept to define. The current drive towards enhancing system safety in the UK has its origins in the Health and Safety at Work Act 1974 (HSE 1974) although this act is often incorrectly associated only with occupational safety. There are many different definitions of safety. For example, the Ministry of Defence (MoD) define safety as "The expectation that a system does not, under defined conditions, lead to a state in which human life is endangered" (MoD 1996a, p.A-3). Alternatively, the British Standards Institution definition of safety is "The freedom from unacceptable risks of personal harm" (BS4778 1995, p.4).

Although these definitions of safety and risk may be intuitively appealing, Ayton and Hardman (1996) argue that a major theme emerging from the literature on risk perception is the emphasis on the inherent subjectivity of the concept. The subjectivity associated with risk can be illustrated by the way that an aircraft accident attracts much more attention than the far greater number of road traffic accidents that occur each year.

It can be argued that there is no such thing as absolute safety and that safety should be defined in terms of acceptable loss or tolerability. The UK Health and Safety Executive (1974) however contend that risk must be quantified and it can be considered tolerable if it has been reduced to the lowest practicable level commensurate with the cost of further reduction. This is known as the ALARP (As Low As Reasonably Practicable) principle which is shown in Figure 2.1.

Despite the difficulties in defining risk, a common theme that links many definitions is that risk is a product of the *probability* of an accident occurring and the *severity* of the potential consequences (Ayton and Hardman 1996; Storey 1996; Leveson 1995; Lowrance 1976). From the previous discussion it is clear that safety and risk are inextricably linked, indeed Bell and Reinert (1993) contend that the task of producing a safety-related system can be seen as a process of risk management.

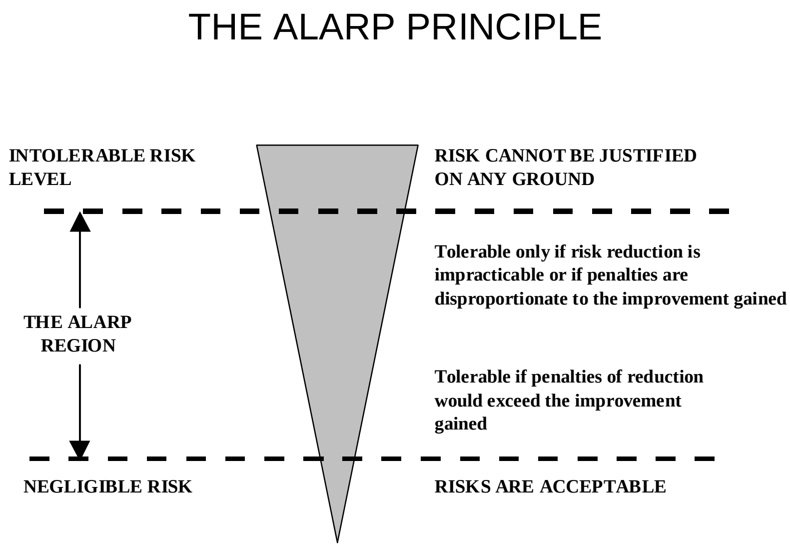

Figure 2.2 – The ALARP Principle for Risk (adapted from HSE 1974)

From this discussion, Lowrance's (1976) definition of safety in terms of risk captured this sentiment succinctly and it will be adopted throughout the remainder of this dissertation:

> *"We will define safety as a judgement of the acceptability of risk, and risk, in turn, as a measure of probability and severity of harm to human health. A thing is safe if its attendant risks are judged to be acceptable"* (Lowrance 1976, p.2).

Designers must understand the issues and develop the skills needed to anticipate and prevent accidents before they occur. Functional safety must be a key component of the system development process and it must be designed into a system from the onset. System developers need different techniques for quantifying system risks and this must be preceded by the identification and analysis of system hazards. These processes are known collectively as System Safety Analysis which will be examined in the following section.

2.2.2 System Safety Analysis

Clare (1997) maintains that safety-related system designers must undertake safety analyses which integrate the concept of hazards with that of risk introduced as discussed in the previous section. To be comprehensive, a system safety analysis must address: hazard identification (what could go wrong); hazard severity (how serious could it be) and hazard probability (what are the chances of it happening); this process will enable an assessment of the system risk. This safety analysis process is summarised in Figure 2.2.

Figure 2.2 – The Safety Analysis Process

Safety-related systems designers must in some way identify the manner in which a system can cause harm in order to improve the safety of a system by preventing accidents before they occur. In simple terms, systems hazards can lead to accidents therefore it is important to examine the fundamental question of what constitutes a hazard in a safety-related system.

Hazards have been defined in a number of ways. Defence Standard 00-56 (MoD 1996a, p.A-2) defines a hazard as a: "*Physical* situation, often following some initiating event, that can lead to an accident". This definition is clearly unhelpful when considering where the hazards lie within a given system; however, it does imply the important point that a hazard will not always result in an accident. Alternatively, Storey (1996, p.33) defines a hazard as a: "Situation in which there is actual or potential danger to people or to the environment". While this is a more system-oriented definition, it could be argued that this definition is too broad as (given appropriate conditions) almost any system state can lead to an accident.

Leveson's definition of a hazard is useful in a systems context:

> *"A hazard is a state or set of conditions of a system that, together with other conditions of the environment of the system, will lead inevitably to an accident"* (Leveson 1995, p.177).

Leveson's (1995) definition is expressed in terms of both the environment and the boundary of the system. This is an important distinction from other definitions as system hazards can only be fully identified and analysed if a system is considered in the context of its operational environment. Leveson's definition however supports the contentious view that a hazard will inevitably lead to an accident. An alternative view of this hazard cause-effect relationship contends that a hazardous situation will not always lead to an accident and that a properly designed system can be returned to a safe state.

From this discussion, a definition of a hazard is proposed which is useful in a *system* context and this definition will be used throughout the remainder of this dissertation:

> *"A hazard is a state or set of conditions of a system that, together with other conditions of the environment of the system, may lead to an accident".*

Having derived a definition for a hazard, it is useful here to examine a widely used technique for the identification and analysis of hazards in safety-related systems.

Hazard and Operability Analysis

One widely adopted technique used for the identification of system hazards is the HAZard and Operability analysis or HAZOP. The HAZOP technique will be reintroduced in Chapter 7 and a brief summary of the technique will therefore be given here. 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 (MoD1995). 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 2.3.

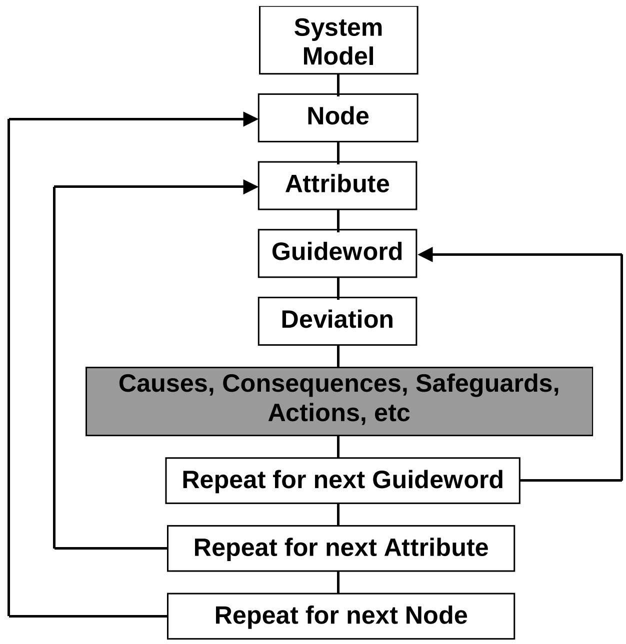

Figure 2.3 – HAZOP Summary

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 2.3 that a HAZOP begins with a system 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 situational 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 2.3.

This HAZOP technique can be used for the identification of hazards relating to both human and technical system factors. However, even using techniques such as HAZOP, a safety analysis of the hardware components of the system, the analysis of hazards and the associated risks relating to the human component of a system is a great deal more difficult and Redmill (1997) contends that the human element is often neglected as a result. This is a particular problem in complex, interactive systems where the HCI designs often ignore, or at least marginalise, key human factors issues which are associated with the context of use. The rationale for a change towards a situated perspective is explored in the next section.

2.3 SITUATED INTERACTIVE SYSTEM DESIGN

2.3.1 A Shifting HCI Perspective

The study of human-computer interaction has evolved from being a relatively minor element of software engineering to a major topic for researchers from a variety of disparate disciplines including substantial contributions from computer scientists, psychologists, and social scientists. Dourish (1995) contends that empirical studies from the many diverse disciplines that contribute to HCI research are gradually producing a change of perspective regarding interactive systems and computer-mediated work in general. HCI has increasingly come to concern itself not just with the mechanism of the interface, but also with a range of related psychological and social issues concerning the context in which human-computer systems are used.

Since the 1970s, the dominant cognitive paradigm in HCI research has been based on the human information processor (Preece *et al.* 1994). From this perspective, everything that is sensed is considered to be information that the mind processes in a series of ordered stages. The notion of information processing has played a fundamental role in HCI by providing a theoretical basis for a cognitive model of human users and this approach is characterised by the ubiquitous model human processor proposed by Card *et al*. (1983).

Although the information processing model has certainly been extremely useful, there is an increasing awareness that there are a number of limitations associated with this paradigm for human cognition (see for example Nardi 1996; Hutchins 1995; Suchman 1987; Winograd and Flores 1986). Proponents of this view 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. 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”. This shift in emphasis when considering cognition requires a holistic approach through careful consideration of the social, organisational and political aspects of HCI in context.

As well as a shift in perspective relating to context, an increasing number of theorists now contend that the subject of consciousness is also important when considering cognition (see for example Nardi 1996; Smith and Hancock.1995). A detailed examination of the dual concepts of context and consciousness is presented in Chapter 4 when the selection of an appropriate research method is discussed. However, from this discussion it may be seen that a comprehensive understanding of human cognition is central to the design of interactive systems, and this is particularly pertinent when the elimination of hazards is a principal concern.

2.3.2 Hazards in Interactive Systems

Interactive systems present unique hazards and problems when developing safety-related systems. Human error is repeatedly mentioned as a major contributing factor or even the direct cause of accidents or incidents. For example, an analysis of causal factors contributing to a situation in which the safety of aircraft was compromised showed that 97.7% of incidents were caused by human error during 1997 (calculated from CAA 1998a and CAA 1998b). Paradoxically, however, many system developers concentrate the majority of their efforts upon technical issues often neglecting human factors.

Woods (1990) maintains that a widespread perception is that the human element is separate from the system and problems therefore reside either in the human or in the technology. Clearly, it is more difficult to predict the possible mental states of an operator in a complex system than the possible physical states of the system being controlled. Even if it were practical to identify all the possible mental states, and their effects on human behaviour, the difficulty of estimating the probability of occurrence of each state remains. Human Reliability Analysis (HRA) has attempted to address this issue, however, much of the HRA research has been dominated by assumptions that apply to technical systems and often these do not translate to human systems (Woods *et al.* 1994). It is argued, therefore, that human error is best examined from a cognitive perspective as traditional reliability engineering techniques do not fit well with human factors issues.

Systems designers often erroneously perceive that incidents attributed to human error are simply indicators that the human element is unreliable and the solution therefore lies exclusively in automating human tasks or in changing human behaviour (Woods 1990). However, Rochlin (1997) warns that automation can introduce new forms of human errors as humans are removed from direct system interaction and thus become passive spectators until an exception occurs. Hollnagel and Woods (1983) suggest that the goals and activities of automated systems are often not well represented in the interface and they maintain that this can be particularly problematic when emergency situations occur. This raises an important question of whether an interactive system should be designed for normal operations that occur for the vast majority of time; or if a system should be optimised for emergency or abnormal operations when the hazards associated with erroneous operation may be far greater.

When designing and evaluating interactive systems it is clearly necessary to consider the cognitive demands associated with normal operations. However, in safety-related systems, it is also necessary to consider emergency or abnormal situations. Berman (1997) argues that many of the human characteristics that should influence the design and optimisation of an interface only manifest themselves during emergencies. Whereas it may be possible to design systems that can assure safety during both normal and emergency operations, systems must often function differently from an operator’s perspective during emergencies. If a safety-related interaction must occur as required during abnormal situations then the hazards associated with the human operator in these systems must be identified and mitigation must be designed into the interface.

As well as the design of the interaction dialogue itself, a safety-related system, such as an air traffic control system, is also only as good as the accuracy of the information presented by the interface. For example, alarm systems play an important role in the safe operation of many interactive systems. Alarm systems often depend on operator situational awareness and corrective human behaviour to mitigate against some intolerable risk in a safety-related system.

Paradoxically, situational awareness is not always synonymous with reliable human behaviour. It is entirely possible for an operator to have good situational awareness and to perform badly. Kirwan *et al.* (1998) found that although one controller was deemed to have superior situational awareness to another, their performance was equal in terms of the air traffic control service provided. Nonetheless, Kirwan *et al.* (1998) suggested that this might not be the case in emergency situations where a performance difference between different levels of situational awareness may manifest itself. When emergencies arise and system operators must react quickly and accurately, the situational awareness of the operator is critical to their ability to make decisions, revise plans and to act purposefully to rectify the abnormal situation.

From this discussion it is clear that the design of the human-computer interface can have a profound effect on safety assurance, particularly during emergency situations. For complex systems in dynamic environments, an operator must pay attention to a large volume of information from a variety of sources, including sensors and other operators, in order to attain an awareness of the situation in question. Billings (1995) maintains that in many cases humans are no longer able to appreciate the true situation without the aid of machines, therefore machines must tell us more of what we need to know and they must do it more effectively and less ambiguously than before. This sentiment emphasises the importance of HCI design for situational awareness in safety-related interactive systems. In turn, operator situational awareness is critical when considering the potential for human errors and their contribution to interactive system hazards which will now be examined

2.3.3 Human Error and System Hazards

Safety-related systems generally contain hazards that originate from both technical and human sources. However, modern technology, particularly IT, is often extremely reliable and hardware reliability engineering is a relatively mature discipline. Consequently, technical hazards are often easy to identify and their associated risks can be quantified with the many different engineering techniques available. In contrast, human-related hazards are relatively difficult to quantify and these are therefore often neglected by systems designers. The central task of the safety-related systems designer is to identify and quantify all significant system hazards associated with both technical and human components. Human error is often the most common, yet neglected, source of hazards in safety-related systems (Woods *et al.* 1994) and this section will take a fresh look at the human contribution to safety and risk.

In his influential work, Reason (1990) contends that human error is inextricably linked with the notion of intention. He asserts that the term error can only be meaningfully applied to planned actions that fail to achieve their desired consequences without some unforeseeable intervention. Reason (1990) identifies the basic types of human error as either slips and lapses or as mistakes. Specifically, slips and lapses are defined as errors which result from some failure in the execution or storage stage of an action sequence, regardless of whether or not the plan which guided the action was adequate to achieve its objective. In this context, slips are considered as potentially observable behaviour whereas lapses are regarded as unobservable errors. In contrast, Reason (1990) defines mistakes as deficiencies or failures in the judgmental or inferential processes involved in the selection of an objective or in the specification of the means to achieve it. This differentiation between slips, lapse and mistakes was a significant contribution to the understanding of human error.

Reason's (1990) error type definitions have their limitations when considering their practical application. When analysing erroneous behaviour it is possible that both slips and mistakes can lead to the same action although they are both the results of different cognitive processes. This can have different implications for the design and assessment of human-computer interfaces. To understand *why* a human error occurred, the cognitive processes that produced the error must also be understood. Broadly speaking, slips or lapses can be regarded as action errors whereas a mistake is a planning error and this characterisation of behavioural errors and the cognitive processes which gives rise to the error types is shown in Table 2.1.

Behavioural Error Type	Erroneous Cognitive Process
Mistakes	Planning
Lapses	Memory Storage
Slips	Execution

Table 2.1 - Behavioural Errors and Cognitive Processes (from Reason 1990, p.13)

Table 2.1 suggests that certain human error types occur because of limitations of the human cognitive processes and these processes must manifest themselves as human performance. Rasmussen (1983) proposed the influential, error based, Skill-Rule-Knowledge (SRK) framework of human performance which is shown in Table 2.2.

Performance Level	Cognitive Characteristics
Skill-Based	Automatic, unconscious, parallel activities
Rule-Based	Recognising situations and following associated procedures
Knowledge-Based	Conscious problem solving

Table 2.2 - Skill-Rule-Knowledge Framework (from Rasmussen 1983)

The three levels of performance in the SRK framework correspond to decreasing levels of familiarity with a task or the task context; and increasing levels of cognition. Based on the SRK performance levels, Reason (1990) argues that a key distinction between the error types is whether an operator is engaged in *problem solving* at the time an error occurs. This distinction allowed Reason (1990) to identify three distinct error types which are shown in Table 2.3.

Performance Level	Behavioural Error Type
Skill-Based	Slips and Lapses
Rule-Based	Rule-Based Mistakes
Knowledge Based	Knowledge-Based Mistakes

Table 2.3 - Human Performance and Behavioural Errors (from Reason 1990, p.56)

Reason (1990) argues that errors mean different things to different people. Moreover, he maintains that practitioners regard errors as the main threat to the safe operation of high-risk technologies whereas, to cognitive theorists, errors offer important clues to the covert control processes underpinning routine human behaviour. Ernst Mach (1905, cited in Reason 1990) said that, “Knowledge and error flow from the same mental sources, only success can tell the one from the other”. Success, in terms of safety, means a reduction of risk through a better understanding of significant cognitive phenomenon enabling the systematic prediction of human error.

The previous discussion suggests that human error originates from different cognitive sources involving both conscious and automatic cognitive processes. Yet, Smith and Hancock (1995) maintain that the concept of *consciousness* was unacceptable in the early 1900s as psychologists were highly influenced by the behaviourist perspective which profoundly influenced the course of research by advocating a simple stimulus-response approach to human behaviour. Nevertheless, consciousness has recently been revived in psychological research, albeit cloaked in different guises such as attention, mental workload and latterly situational awareness. Situational awareness is a relatively new concept that has captured the imagination of those who are interested in the role of humans in complex systems. Chapter 3 will present a detailed examination of situational awareness in the context of its applicability to the design and evaluation of safety-related interactive systems. To provide a basis for this discussion, the following section will examine why situational awareness is important when considering the safe design of interactive systems.

2.3.4 Conscious Design for Safety

In complex systems the operator's situational awareness can be significantly influenced by the design of the interactions and the interface. Without careful consideration for the operator, interfaces in particular often evolve to become confused, disparate fields of data. Clearly, there are unique HCI design requirements relating to situational awareness and it is important to examine how these might be related to usability requirements and addressed for the development of safety-related interactive systems.

The concepts of conscious and automatic cognition correspond to what Norman (1993) has called *reflective* and *experiential* cognition. Norman (1993) argues that focusing on these two modes of cognition enables us to highlight and compare different aspects of mental behaviour. He contends that experiential cognition involves the skill of an expert responding automatically to events – without conscious reflection or awareness. In contrast, he maintains that reflective cognition requires different mental processes based on a higher level of consciousness. Norman (1993) also makes the important point that both modes of cognition are needed and neither is superior to the other – they simply differ in requirements and functions. Cognitive requirements are particularly significant when designing the interactions of a safety-related system to support conscious or automatic cognition.

Norman’s (1993) classification of cognition is aligned with the SRK-based framework of human behaviour proposed by Rasmussen (1983) which was examined in the context of human error in section 2.3.3. The SRK framework suggests that human behaviour occurs as a result of different levels of cognition and, implicitly, different levels of consciousness. For example, human behaviour at the skill level, such as an experienced driver changing gears in a car, occurs automatically and without conscious effort; this is an example of action arising from experiential cognition. From a practical perspective, the difference between automatic and conscious cognition, which manifests itself as skill, rule or knowledge-based human behaviour, is an important consideration. However, there is no agreement on how this should be implemented in interactive systems.

System interactions should support users in achieving their tasks, and the design of the interface can have a tremendous affect on the safety of the system (Rajan 1997). Interaction breakdowns can occur when human-computer communication is interrupted – in a safety-related system this could have potentially lethal consequences. Winograd and Flores (1986) maintain that interaction breakdowns occur when a system behaves differently than was anticipated by the user – when automatic cognition becomes conscious. They also contend that interaction breakdowns can trigger an inappropriate action (an act of commission) or it may fail to trigger an appropriate action at all (an act of omission).

An interaction breakdown clearly causes an operator to apply a proportion of their finite cognitive resources to the interaction and not to the system objective. Therefore, it can be argued that interaction breakdowns could be disastrous in a safety-related system such as an aircraft or an air traffic control system if the operator must stop flying or controlling in order to interact with the system. Based on this understanding, it may be argued that the aim of HCI design should be to eliminate any potential interaction breakdowns, to develop a *transparent* interface that requires minimal conscious cognition. This sentiment is prevalent within the HCI literature. For example, Norman (1993) argues that interruptions are especially common in the interactions with computer systems and he suggests that to achieve ‘optimal flow’ (automatic interaction) it is necessary to minimize these interruptions. He argues that a properly designed tool will ensure that experts use them subconsciously, automatically, “the tools, the person, and the task meld into a seamless whole” (Norman 1993, p.34).

However, it can also be argued that the greatest hazard in a system is associated with the operator experiencing when he should be reflecting - in other words undertaking automatic processing when conscious thought is required. With experience, automatic human cognition can become the norm; information is perceived, interpreted and acted upon with little or no attention to it. For example, many skilled functions of an air traffic controller possess this characteristic and, for some controllers, it is intrinsic to skill acquisition. Conscious cognition bears a complex relationship to situational awareness and Hopkin (1995) maintains that it seems intuitively unsafe to perform tasks while remaining unaware of them even if they are performed well. The implication is that operator awareness of a situation may not be updated and may therefore be inaccurate.

What remains unclear is how to develop specific interactions to support the cognitive processes involved in acquiring and maintaining situational awareness. On the one hand, it can be argued that interactions in complex, dynamic systems should be transparent and thus should require only automatic action from an operator. On the other hand, it could be that automatic interactions circumvent the consciousness of the operator leading to an erroneous state of awareness and, ultimately, behaviour which may be unacceptable in safety-related contexts.

Recall Norman's (1993) explanation of experiential cognition involving the skill of an expert responding automatically to events - *without conscious reflection or awareness*. An important issue arising from this discussion is, how system designers can assure the safety of a system which is often designed specifically so that an operator can interact automatically (perhaps with hazardous consequences). The following section will begin to address this question by discussing the life-cycle activities that must be undertaken to generate the data required by system developers to enable them to provide safety assurance for interactive systems.

2.4 SAFETY ASSURANCE FOR INTERACTIVE SYSTEMS

2.4.1 The Safety Life-Cycle

Storey (1996) maintains that systems must not only be safe – they must also be shown to be safe and this sentiment emphasises the importance of appropriate safety analysis techniques and methods for system developers. Ultimately, system operators must convince regulatory authorities that their systems are safe to operate, therefore it is also necessary to identify the unique safety analysis activities relating to interactive systems. Safety-related system developers must undertake different safety analysis activities throughout the system life-cycle. These can broadly be characterised as either exploratory or confirmatory as shown in Figure 2.4 which is adapted from the STARTS (1989) 'V' System Life-cycle Model. This diagram will be referred to later in section 8.3 of this dissertation when discussing interactive safety analysis techniques specifically relating to the analysis and evaluation of situational awareness.

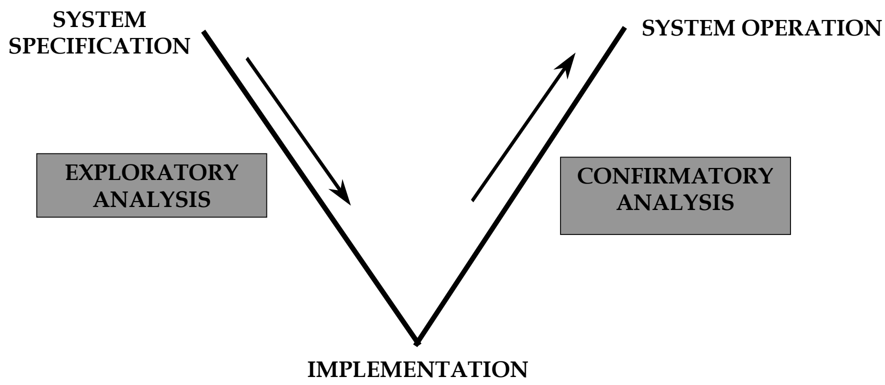

Figure 2.4 – A Safety Life-Cycle (adapted from STARTS 1989)

Historically, there has been a general reluctance to use computer-based systems to control safety-related processes. Leveson (1986) argues that the techniques used to analyse systems without software are only designed to cope with random failures and that system designers ignore human design errors (systematic errors) since it is assumed that all failures caused by human errors can be avoided completely or removed prior to delivery and operation. Perrow (1984) also argues that human errors are inevitable in all complex systems containing software. If these compelling arguments are accepted, the use of software in complex systems highlights an essential requirement for appropriate safety analysis techniques for systems containing interactive software components.

Ideally, exploratory analysis techniques should enable a system developer to identify interaction hazards as early in the life-cycle as possible to reduce the potential cost of system redesign and rework. However, this ideal must be balanced against a requirement to analyse system interactions in context which implies the availability of a fully functional system and an advanced prototype may be the minimum practical requirement. Confirmatory analyses can be used later in the life-cycle both to generate numerical safety case data and to highlight hazardous areas of an interactive system design that may require additional risk reduction through redesign. From the previous discussion, concerning the importance of situational awareness in complex, interactive systems, it follows that appropriate exploratory and confirmatory analyses techniques must be developed to evaluate this critical phenomenon in context. The following section will explore the issues behind the requirement to generate safety case evidence through appropriate system safety analyses.

2.4.2 Generating Safety Case Evidence

In some industries a safety case is a mandatory requirement to provide a documented body of evidence that a system is tolerably safe for a given application in a given context. For example, in the UK, National Air Traffic Services are required to produce safety cases for air traffic control systems to satisfy the air traffic control service Safety Regulation Group. Broadly defined, a safety case is a report that consists of claims about a system and evidence which is used as the basis of a safety argument to support those claims. This relationship is shown in Figure 2.5.

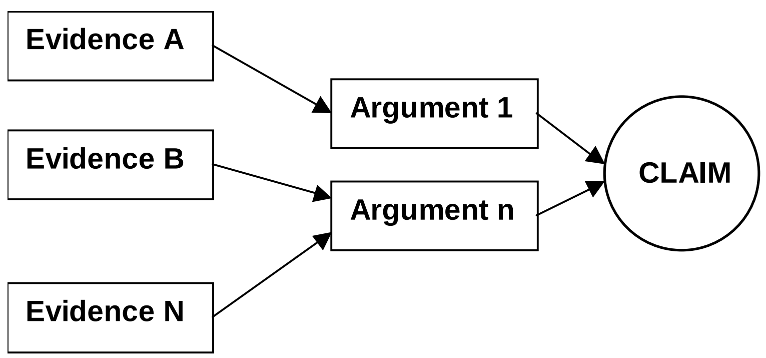

Figure 2.5 – A Safety Claim Relationship

Safety arguments, particularly those relating to system hardware components, are often based on evidence taken from reliability data and historical trends. It is often much more difficult, if not impossible, to derive reliability evidence to support safety claims relating to the human factors within a system. Having discussed some of the hazards unique to interactive systems in section 2.3.2, a requirement has been identified to generate appropriate evidence to support interactive system safety case arguments. However, it is difficult to obtain appropriate evidence to support a convincing argument that interactive systems are tolerably safe using existing (hardware biased) safety analysis techniques and this can be a major problem when a safety case must be produced.

It is suggested here that situational awareness can provide safety-related interactive systems designers with a measure of the degree of safety through the quantification of an operator's awareness of the safety-related elements of a particular situation. It will be shown in Chapter 3 that situational awareness can be considered as the degree of dynamic coupling between an operator's awareness and a particular situation. Accepting this assertion for the moment, it follows that a safe system would require the development of interactions to support the cognitive processes involved in acquiring and maintaining situational awareness. What remains is to develop practical analysis techniques for this complex cognitive phenomenon that can be applied in both the exploratory and confirmatory phases of the system life-cycle.

For interactive systems where human errors can lead to death or injury, safety is paramount and developers must ensure that the correct design trade-offs are made. It is suggested here that safety is not always synonymous with usability and that usability and safety requirements can be mutually exclusive depending upon the context of the interaction. If a well-intentioned system developer attempts to eliminate interaction breakdowns in the name of usability, this may have an adverse effect on the situational awareness of the operator.

It is therefore essential for safety-related system developers to carry out hazard analyses at appropriate life-cycle stages to identify and quantify the risks associated with system interactions and to construct convincing safety arguments based upon valid evidence. If this argument is accepted, it follows that it is vitally important to develop safety analysis techniques for the identification of situated interaction hazards to provide developers with guidance on safe design trade-offs. Also, to have practical application, interactive safety must be specified in quantifiable or measurable terms in a similar manner to usability to provide valid evidence for safety case arguments.

2.5 SUMMARY

This chapter has provided an explanation of functional safety in the context of complex, interactive systems situated in dynamic environments. This was done to provide the reader with an understanding of the concept of functional safety and a common vocabulary of safety terminology which will be used throughout the remainder of this dissertation. The chapter has also provided the basis for a detailed discussion on situational awareness and its relationship with interactive system safety which follows in Chapter 3. The chapter has provided an explanation of the risk-based approach to safety management which has been advocated by the UK Health and Safety Executive and consequently has been adopted by many regulated sectors of industry throughout the UK. An explanation was also provided on the importance of human factors and specifically how human error can contribute to the majority of interactive system hazards.

A shift in perspective within the HCI community has been explored in this chapter in order to highlight the scope of hazard analyses required for interactive systems to include psychological and social factors in the context of system use. It has also been suggested that safety is not always synonymous with usability and usability and safety requirements can therefore be mutually exclusive depending upon the context of the interaction. It was also suggested that it is vitally important to develop safety analysis techniques for the identification of situated interaction hazards to provide developers with targeted guidance for the reconciliation of conflicting usability and safety requirements.

The chapter has explored the requirement to generate safety case evidence through appropriate system safety analyses. The chapter has also presented an argument for evaluating and quantifying system safety in terms of the level of situational awareness acquired through interaction with the system. The chapter concluded with a discussion on the rationale for the different exploratory and confirmatory safety analysis activities undertaken during the system life-cycle to generate appropriate evidence upon which interactive system safety arguments can be constructed and system safety assurance can be provided.

Chapter 3

EVALUATING SITUATIONAL AWARENESS

3.1 INTRODUCTION

It was suggested in Chapter 2 that an evaluation of Situational Awareness (SA) could provide system designers with a measure of the degree of interactive system safety. It was also argued that this can be achieved through an integrated evaluation of the level of awareness acquired through interaction with the system and with an analysis of the process of acquiring and maintaining SA. Endsley (1995a) contends that the enhancement of SA has become a major design goal for those developing interfaces in safety-related interactive systems. Billings (1996) also maintains that in many cases humans are no longer able to appreciate the true situation without the aid of machines therefore machines must tell an operator more of what they need to know and they must do it more effectively and less ambiguously than before. Clearly, SA should be a major safety consideration when developing interfaces for interactive systems.

The aim of this chapter is to provide an understanding of the central topic of this research through a critical review of the literature relating to SA. This chapter draws together the safety-related interaction design issues introduced in the previous chapter and relates these to the conclusions drawn from a detailed literature review focusing on SA. SA is a complex phenomenon without an accepted definition (Charness 1995; Hopkin 1995) therefore this chapter will examine the theoretical foundations and the dominant perspectives of SA. A major conclusion to be drawn from this literature review is the importance of an integrated evaluation of both the *process* of acquiring SA and the state of awareness that the operator has acquired (*the product*). A number of major themes which are considered important will be drawn from the review of the different theoretical perspectives on SA to form the basis of a Situated Cognition perspective of SA.

An objective of this research is to develop a general method for evaluating the safety of an interactive system in terms of its relative support for SA and safety. Having proposed a Situated Cognition perspective on SA, this chapter will therefore examine the validity and reliability of the different techniques available for analysing and evaluating both the process and the product of SA in context. A detailed explanation of the chosen techniques will be presented in Chapter 4. This chapter also identifies the theoretical limitations associated with the models available to system developers for analysing the process of acquiring and maintaining SA and a requirement for a dynamic SA Process Model is identified. Such a model would provide an essential tool for an SA analysis method which is an objective of this research.

3.2 SITUATIONAL AWARENESS - A PERSPECTIVE

3.2.1 A Critical but Ill-Defined Phenomenon

Sarter and Woods (1991) identify SA as a critical, but ill defined, phenomenon in complex, dynamic systems. They also suggest that SA is an essential pre-requisite for the safe operation of any complex, dynamic system. SA is itself a complex concept and it is therefore difficult to find an accepted definition of the term (Charness 1995; Hopkin 1995). Nonetheless, SA has been the subject of much research in recent years, particularly within the field of aviation and other similarly complex domains (see for example Harris 1997; Garland and Endsley 1995). This section begins with an examination of the theoretical foundations of SA and the rationale for this research.

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 (1995c) argued that a commonly accepted definition is a particular requirement for practitioners attempting to design and evaluate systems that rely upon operator awareness. SA becomes particularly important when the operator’s awareness is deemed to have a significant impact upon system safety. By focusing on SA as a major design goal the emphasis shifts from an anthropometric approach, matching the system to the physical characteristics of the user, to a focus on the cognitive ergonomics, concentrating on the mental work.

In the context of human-machine interaction, current definitions of SA are generally based on opposing views of SA as either a cognitive phenomenon or as an observer construct; these can respectively be referred to as 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 Interactionist perspective regards SA as an abstract concept located 'in the interaction' between actor and environment. Despite this fundamental divergence, there are conceptual similarities between the different perspectives of SA and this conformity can be used to help understand the concept in the context of safety-related interactive systems. Figure 3.1 depicts the prominent perspectives of SA which will be examined in detail in the remainder of this section before a definition based upon common themes taken from these perspective is proposed.

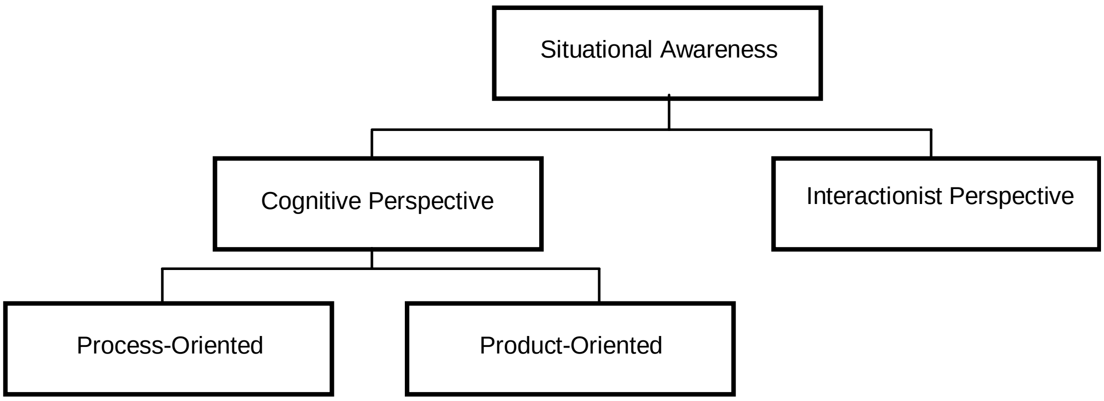

Figure 3.1 – Dominant Perspectives of Situational Awareness

3.2.2 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. A typical process-oriented definition of SA has been proposed by Sarter and Woods:

> *"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 (1995a, 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, SA has also been defined as both a product and process as in the following definition by Issac:

> *"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 individual 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.

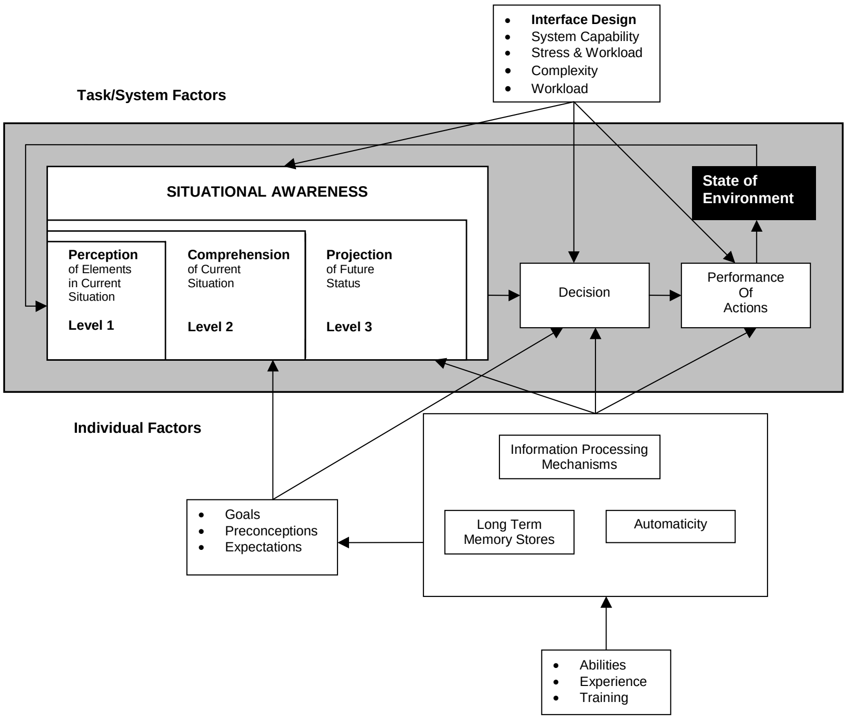

Figure 3.2 – A Typical Cognitive Model of SA (Endsley 1995b, p.35)

Nonetheless, Endsley's (1995b) theoretical model of SA (shown in Figure 3.2), 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. Figure 3.2 presents a typical cognitive perspective of SA and this model proposes three different levels of SA which are relevant to this dissertation:

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

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

- Level 3 SA. *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.

This leads to another common notion that is particular to a cognitive perspective whereby SA is often considered synonymously with mental models (Gentner and Stevens 1983). For example, Isaac (1997) maintains that the ability to produce a mental representation of a situation enables an air traffic controller to regain and maintain SA and she proposes a model (Figure 3.3) that depicts an explicit link between SA and the production and use of mental models using Endsley’s three levels.

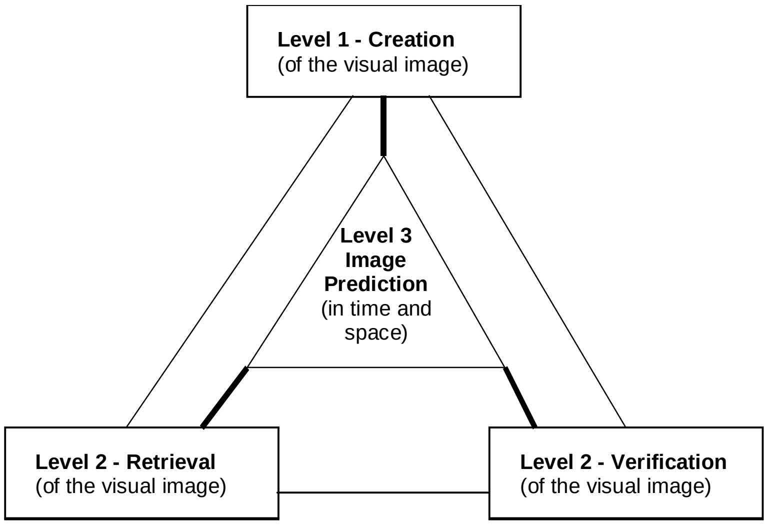

Figure 3.3 – Mental Models and SA Levels (adapted from Issac 1997, p.187)

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 representation, generally referred to as ‘the picture’ (Whitfield and Jackson 1982), can be visual, verbal or both. A mental model may be regarded here as a dynamic mental representation of a situation that allows people to make predictions about future states and to make inferences regarding situations not experienced before (Woods *et al.* 1994). Clearly, there are striking similarities between this general definition of a mental model and Endsley’s (1995b) process-oriented definition of SA given previously.

3.2.3 Developing Interactionist Perspectives

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 explained as an abstraction that exists only in the mind of the researcher. 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 marginalising) 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 this 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 marginalise the mental state as a concern and focus on explaining SA without reference to the user's cognitive processes.

3.2.4 A Situated Cognition Perspective

A synthetic and 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 acting, reflecting a move away from traditional information processing models of cognition towards the situated cognition (and situated action) perspective introduced in Chapter 2 as a developing movement in HCI.

A Situated Cognition perspective of SA would address how the current awareness of a situation effects 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 (shown in Figure 3.4) to reflect his assertion that *active perception* will unavoidably encounter unexpected situational elements or even fail to find them.

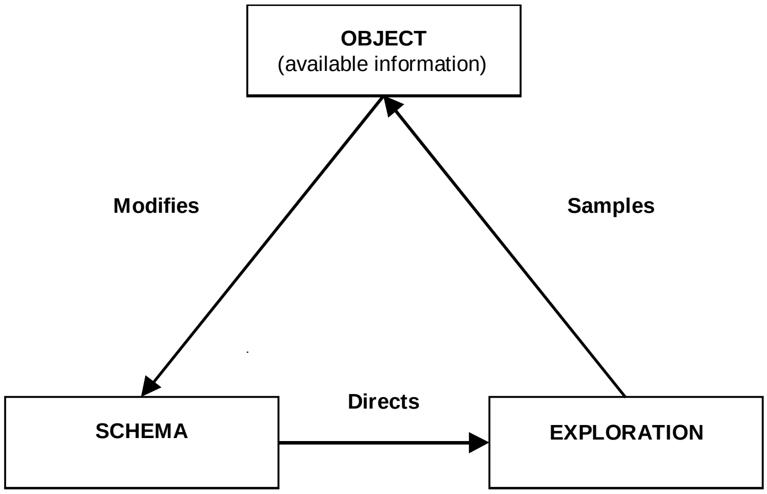

Figure 3.4 – Perception-Action Cycle (adapted from Neisser 1976)

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.

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. There is also significant on-going research to further these debates and refine the perspectives. Whilst such research is of long-term value in contributing to the maturity of the field and refining explanations of SA, this dissertation takes a more pragmatic approach, arguing that an attachment to a particular perspective can cause problems. Where there is contention between opposing perspectives, research can tend to become dogmatic which in an immature area may lead to opportunities for furthering our understanding being missed as researchers endeavour to strengthen their particular perspective.

To achieve the objectives of this research, it is considered vital to avoid dogma and to fully consider the different research perspectives relating to SA; synthesising constructs from the existing perspectives may help to make more sense of the situations which are the focus of this research. Accordingly, four important themes will now be drawn from the theoretical perspectives discussed and these themes will be used as a framework to develop a situated cognition perspective for the evaluation of SA.

Theme I: 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.

Theme II: Situated Action

An area that is seen as important, but on which there is much disagreement, is consciousness. Compare, for example, the description of Endsley’s (1995b) model of SA with that prescribed by Smith and Hancock (1995). This tension reflects the broader ‘cognitive’ debate in HCI introduced earlier in section 2.3.1. Whilst the information-processing view within the cognitive paradigm has contributed substantially to psychology-oriented research, there is a growing view that it is limited and presents a constraint to the advancement of theory in the area. 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 consciousness and its contribution to situated action or ‘purposeful action’ (Suchman 1987), and reflect that an individual’s awareness of a situation consciously effects the process of acquiring and interpreting new information in an continuous, proactive cycle.

Theme III: Context

The positions taken in themes I and II reflect the importance of the individual 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 individual 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 is one which has emerged as a theme of increasing importance in cognitive science and HCI, as noted in section 2.3.1.

Theme IV: Dynamism

When an individual 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 individual. The continuous information extraction process in which the individual is engaged implies that SA requires individuals 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 individual.

SA is a critical but ill-defined phenomenon for complex, interactive system operators. 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 a Situated Cognition approach to SA which is based upon a subjective synthesis of important concepts derived from a critical review of the different theoretical perspectives. In the remainder of this dissertation it will be shown that a useful outcome of such an approach is a perspective that helps system designers understand SA and its usefulness in designing interfaces to, and interaction sequences and dialogues within, safety-related systems.

A major conclusion to be drawn from this literature review is the equal importance of evaluating both the process of acquiring SA and the state of awareness that the operator has acquired (the product). An objective of this research is to propose and validate a general method for evaluating the safety of an interactive system in terms of its relative support for SA. Having undertaken a critical literature review to determine a perspective on SA; it is now important to examine the theory relating to the different approaches for analysing and evaluating both the process and product of SA in a systems context.

3.3 EVALUATING SITUATIONAL AWARENESS IN CONTEXT

3.3.1 Context and Validity for SA Evaluation

The question of context is vitally important to the Situated Cognition perspective of SA. Flach (1996) points out that there has been a tension between basic and applied research within the human factors community for some time. He maintains that the basic science of psychology and human performance, generally considered to be the foundation which underpins human factors, is largely a science based on ‘nonsense tasks’ which are chosen specifically because they are context independent. This perspective is based upon a recognition that experimental psychology is a science where context has often been considered a confounding factor rather than an integral part of the problem.

The requirement to assess SA in context leaves a choice of either observing operational tasks in real-time or undertaking high-fidelity simulations using representative task scenarios. This choice presents a problem as the focus of this research is primarily interested in *safety* and it is highly unlikely that *safety-related* interactions will be observed in real-time unless either a long-term study is undertaken or real hazards are intentionally introduced. A long-term study is not a feasible option for this research and clearly it is not possible to compromise safety by introducing real hazards into an operational environment. It follows, both for this research project and generally, that the only practical method of analysing and evaluating SA in a safety-related environment without compromising safety is to use simulations. It is therefore necessary to discuss the validity and reliability of the different techniques available.

From the discussion in section 3.2.1, is follows that a valid measurement of a cognitive concept such as SA cannot simply be inferred directly from a measure of human performance in a simulated environment. To be useful for this research, a suitable method must address the wider issues associated with the context of measurement including the systems and simulation scenarios used. Endsley (1995c) criticises the validity of every SA measurement technique except those using operationally realistic scenarios arguing that only scenarios with 'full face validity' are appropriate for the measurement of SA. Pew (1995) however takes the more eclectic view that any simulation involves compromises and he argues that the issue of validity is only one of degree and that the degree of validity required for a particular scenario depends on the purpose of the assessment.

It is highly impracticable (and even unethical in stressful situations) for a simulation in a safety-related environment to be undertaken with the subjects unaware of the artificiality of the associated risk to human life. It seems that a degree of invalidity must be accepted as the subjects must be made aware that the risks to safety are artificial, and it follows that this will bias the evaluation of any variable in context as the Hawthorne Effect (Burnes 1996) comes into force.

However, an objective of this research is to provide a general method for evaluating the safety of an interactive system in terms of its *relative* support for situational awareness. It is not a requirement, nor is it possible, to calculate an *absolute* measure of SA relating to a particular interactive system through simulation which, as pointed out, involves a degree of compromise. The best that can be achieved is to limit the artificiality of the simulation by ensuring that the task scenarios, operating environment and SA evaluation method do not compromise 'full face validity'.

3.3.2 SA Evaluation Techniques

To ensure that simulation validity is not compromised the most suitable evaluation methods must be chosen. Consequently, an assessment of the strengths and weaknesses of the different SA evaluation techniques follows which is based upon Endsley's (1995a) taxonomy:

Physiological SA Evaluation

Studies have been undertaken which have attempted to evaluate the product and process of SA through such techniques as Electroencephalographic measurements and eye-tracking. Although these studies have shown some promise in assessing the process of acquiring SA they are not generally suitable to evaluating the state of awareness. The link between looking at situational information and the internal comprehension required for SA modification is also uncertain. Finally, these techniques generally require the use of specialist equipment which can be extremely intrusive in an operational context. Physiological SA evaluation will not be considered further in this dissertation.

Performance-Based SA Evaluation

Performance-based measures of SA are generally objective and are not usually intrusive. However, system measures are based upon observed behaviour and these are usually too coarse to reveal subtle differences when comparing relative system design solutions. Global measures give only the end result of a number of processes that can contribute to the overall performance such as poor decision making or slips and lapses for example. In the context of this research, making an explicit link between performance and SA could mask the explicit contribution of the HCI design. It is possible to collect detailed SA performance data relating to specified subtasks; this however increases the risk of missing performance data related to a hazardous interaction between unspecified tasks. Ideally, a measure of SA in isolation is required to capture the entire system context and to assure system safety. This research is concerned with the evaluation of all hazardous system interactions and their impact upon SA therefore performance based SA evaluation methods will not be considered further.

Subjective SA Evaluation

Subjective SA evaluation techniques can be either self-rating or observer-rating and several methods have been developed to subjectively assess SA in a systematic manner. One popular technique is Situation Awareness Rating Technique (SART) which has been shown to correlate with performance measures (Taylor 1990) notwithstanding the limitations of these measures discussed above. In general, however, the subjectivity of this approach when rating SA has several limitations. If the subjects are asked to rate their SA during a simulation this is too intrusive and if it is done after a simulation hindsight bias can be a problem. If the SA rating is done by a knowledgeable evaluator the only information available is that which is available directly through observation; external rating does not provide access to the internal awareness upon which operator actions are based. Based on these limitations, subjective SA evaluation techniques will not be considered further in this dissertation.

Questionnaire-Based SA Evaluation

Questionnaires can provide comprehensive data which can easily be compared with real situations to give a measure of all the system elements that contribute to SA. Questionnaires also provide a measure of SA where information is elicited directly from the subject without any observer (mis)interpretation. Questionnaires can be administered in real-time during a simulation; however, the process of understanding the questions and forming the answers can interfere with SA. This is particularly pertinent in the complex, dynamic environments which are the subject of this research. Alternatively, the subject can be questioned after the simulation with the associated risk of memory decay and hindsight bias affecting the results. To overcome these limitations some researchers have developed SA evaluation techniques that rely on freezing the simulations at various intervals and administering SA-related questions. One such technique, which has been widely cited and applied, is the Situational Awareness Global Assessment Technique (SAGAT) developed by Endsley (1995c). This discussion suggests that a questionnaire-based evaluation technique such as SAGAT would be suitable for this research.

To achieve the objectives of this research project, it is necessary to choose SA evaluation methods for this research that:

- Measure SA and are not simply a reflection of other cognitive processes.

- Provide the required insight in the form of a global measure which can capture the entire system context contributing to SA.

- Do not substantially affect the subject's SA which would provide biased data and altered behaviour.

It has been suggested here that there are a number of reasonably mature and widely accepted techniques available for evaluating the product of SA (SART, SAGAT, etc.). The discussion suggests that the most suitable method for evaluating the state or product of SA would be a questionnaire-based evaluation technique.

However, it was also argued that any comprehensive evaluation of SA must address both the *process* of acquiring and maintaining SA and the *product* of SA itself. Models and techniques for analysing the process of SA however are entirely dependent upon the underlying Cognitive or Interactionist perspectives which, as discussed, have their limitations. As a result, an SA Process Model which is based upon the Situated Cognition perspective of SA is identified here as an essential requirement towards the development of an integrated analysis of SA. An SA Process model must also be consistent with the philosophy of the chosen research method therefore a detailed explanation of an SA Process Model will be provided in Chapter 4 following an explanation and justification of the research method chosen for this dissertation.

3.4 SUMMARY

This chapter has provided an understanding of the central topic of this research through a critical review of the literature relating to SA. The chapter examined the theoretical foundations and the dominant Cognitive and Interactionist perspectives of SA in order to derive a pragmatic view founded upon a Situated Cognition perspective. A major conclusion from the literature review is the equal importance of an integrated evaluation of both the process of acquiring SA and the state of awareness that the operator has acquired (the product).

Having proposed a Situated Cognition perspective on SA, this chapter then examined the validity and reliability of the different techniques available for analysing and evaluating both the process and the product of SA in context. The examination suggested that the most suitable method for evaluating the state or product of SA would be a questionnaire-based evaluation technique. The chapter has also identified the theoretical limitations associated with the models available to system developers for analysing the process of acquiring and maintaining SA and a requirement for the development of an SA Process Model based upon a Situated Cognition perspective was identified. It has been argued that such a model would provide an essential tool for an SA analysis method and a detailed explanation of an SA Process Model will be provided in Chapter 4 following a reasoned explanation of the research method chosen for this dissertation.

Chapter 4

AN ACTIVITY-BASED SAFETY ANALYSIS METHOD

4.1 INTRODUCTION

In Chapter 3 it was suggested that a Situated Cognition perspective of SA must support an integrated approach to the evaluation of SA where both the process of acquiring SA and the state of awareness that the operator has acquired (the product) are equally important. It follows that an integrated approach to the evaluation of SA would provide system designers with a measure of the degree of interactive system safety. In Chapter 2 it was explained that the dominant cognitive paradigm in HCI research in recent years has been based on the model human information processor (see Card *et al.* 1983). It was also explained that there is a growing awareness of the limitations associated with this reductionist model. A number of new theoretical approaches have been proposed which consider the situated nature of human cognition and new cognitive models may be derived from these.

Activity Theory (AT) is one theoretical approach that allows researchers to capture the richness of human activity through a research approach oriented toward studies of work in context (Hasan 1998). The AT approach was expected to be particularly appropriate for this research which focuses on the situated cognition and activity of system operators when acquiring and maintaining SA. This chapter will explore the potential of Activity Theory, briefly introducing the theory and the key principles which it embodies. The aim of this chapter is to present a case for using AT as the basis for an integrated analysis of situated interaction hazards in safety-related systems.

It was argued in Chapter 3 that operator SA is a critical safety attribute that is acquired and maintained through a process of situated human activity and a requirement was identified for the development of a model of the SA process. An SA Process Model is proposed in this chapter based upon the Situated Cognition perspective developed in Chapter 3. This chapter will show how the SA Process Model is also founded upon the principles and philosophy of Activity Theory. The chapter will then outline an SA Process Analysis Technique that uses both the SA Process Model and the principles of AT to analyse situated interaction hazards in context.

The chapter will discuss the selection and adaptation of Endsley’s (1995c) Situation Awareness Global Assessment Technique (SAGAT) for evaluating the product of SA acquired by a system operator. Finally, this chapter will outline an initial proposal for an Interactive System Safety Analysis Method (ISSAM), an integrated approach to the application of Activity Theory using the SA Process Analysis Technique together with SAGAT as an analytical framework for evaluating SA. ISSAM will be developed through a field study of a complex, interactive system which is presented in Chapter 5 and explained in Chapter 6.

4.2 SITUATED ACTIVITY AND INTERACTIVE SYSTEMS

The starting point for any systematic analysis of HCI is an understanding of *how* and *why* users perform activities. Task analysis techniques are often used within the HCI community to capture *how* an activity is performed. The general purpose of task analysis is to observe the entirety of a user’s interaction within a particular system, including both social and individual activities, and to produce a description containing all of the information necessary to conduct a particular task. However, it is often difficult - if not impossible - to provide a complete description of human activity as task analysis techniques and methods cannot capture either the *tacit* knowledge or the fluent action in the actual work processes that are often required in skilled activities (Bannon and Bødker 1991).

To understand *why* an activity is performed it is necessary to consider both individual and collective cognition in a specific context. Understanding the ‘how’ and ‘why’ of activity in context becomes even more important when considering how people must work within safety-related systems. By their nature, safety-related systems present unique hazards and problems arising from the interactions between the user and the system. Human error, for example, is repeatedly mentioned as a major contributing factor or even the direct cause of incidents or accidents involving safety-related systems (Hollnagel 1993).

To help avoid human errors, new theories and models of work are required for capturing the richness of human activity in context and for framing analyses of how and why activities are performed – particularly when safety is an issue. A number of alternative theories have recently emerged and AT is one promising theoretical approach for situated studies of work.

AT is not a new approach and it has been applied by Soviet psychologists and social scientists since the 1920s; however, attempts to apply AT to other fields, including HCI, have only recently been made. The AT perspective suggests a radically reformed framework for the study of human-computer interaction from that provided by the human information processor perspective. In AT the basic unit of analysis is the activity which is considered to be the *minimal meaningful context* required to understand situated actions. Perhaps the most fundamental implication of this shift in perspective is the explicit realisation that computer-mediated activity deals with two interfaces: the human-computer interface and the human/computer-environment interface.

Using AT as an analytical framework broadens the system view as it leads to an examination of system users and the social setting in which they operate the system. A particular area in which this perspective might be useful is in the design and evaluation of safety-related systems, where researchers have begun to consider hazards that might arise through the design of the interactions between the system, its users and the work context in which they operate. These interaction hazards are very different from those which have historically been the concern of safety-related systems since they arise directly from the *use* of the system and require some understanding of the cognition of users *in situ*.

4.3 AN INTRODUCTION TO ACTIVITY THEORY

Activity Theory (AT) can be broadly defined as a philosophical framework, drawn from Soviet psychology, for understanding the richness of human activity in social contexts. AT has its own terminology which can initially be hard to penetrate and it is tempting to try to alleviate the problem by using more familiar terms; however, this approach has generally been resisted unless clarity is affected.

It is useful here to provide a brief introduction to AT before a description is given of how AT has been applied in a specific context for the study of work. However, an in-depth explanation of the philosophical foundations of AT is beyond the scope of this dissertation and readers are directed to the work of Leontiev (1978; 1981) and Vygotsky (1978) for more detailed discussions. It should also be recognised that there are numerous different interpretations of AT and the explanation given here is primarily informed by the work of Engeström (1987), Bødker (1991) and Nardi (1996b).

The basic unit of analysis in AT is the activity and a model of the structure of activity as proposed and adapted by numerous activity theorists will therefore be examined (Kuutti 1996; Engeström 1987). A closer examination of this activity structure model provides a basis for discussing the principles of AT and an appreciation of these key principles will later enable the consideration of the applicability of AT for analysing safety-related systems.

4.3.1 The Structure of Activity

AT deals with the activity of transforming something to achieve an objective while avoiding the dichotomies between thought and action or between individuals and society which are prevalent in western philosophy (Blackler 1993). The basic unit of analysis in AT is human activity which is motivated by the need to achieve an objective. In AT terminology, the term *activity* is intended to convey the essential connotation of physically or mentally 'doing in order to transform something' and the term *object* is used in the sense of an objective (Kuutti 1996).

An influential model of activity (shown in Figure 4.1), based on the conceptualisation by Engeström (1987), can be used to show the structure of activity and to highlight the key principles of AT. Figure 4.1 depicts the three main relationships between the individual (subject of the activity), objective (object of the activity) and social group (community) involved in an activity. It should be noted that all the elements of the activity are related; however for the sake of clarity not all of these connections are shown in Figure 4.1. It can be seen from this model that the object of an activity is transformed by the participants through a transformation process. The model also depicts the reciprocal relationship between the subject and the object of an activity and it shows that this relationship is mediated by an artefact or tool.

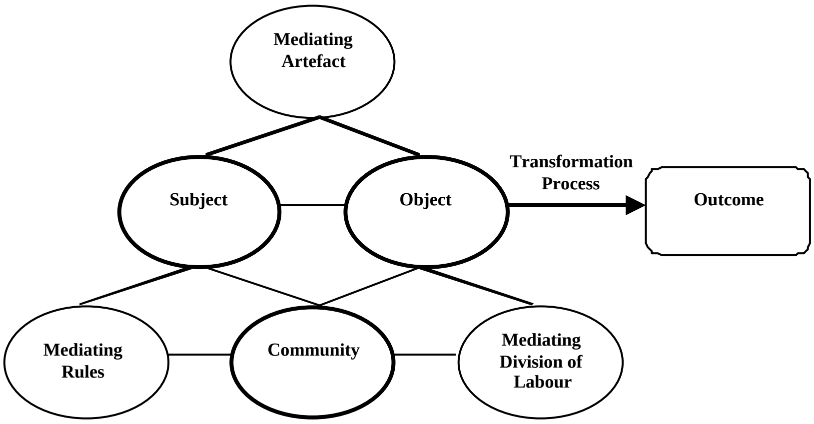

Figure 4.1 – Structure of Activity (adapted from Engeström 1987, p28)

This activity structure model illustrates that an individual's actions towards an objective will be mediated not only by the tools used - but also by the rules and division of labour of the community to which the subject belongs. It is important to realise that in AT the two-way nature of these relationships depicts the fundamental principle that the cognitive processes of an individual will affect their environment which in turn will be affected by the tools, rules and division of labour involved in the activity. The AT philosophy is in marked contrast to the 'behaviourist' view of psychology (or the naturalist view of philosophy) where the simple stimulus-response relationship between the environment and a subject predominates.

4.3.2 Principles of Activity Theory

The activity structure model in Figure 4.1 shows that AT is based on a number of fundamental, philosophical principles, which will be briefly considered here. These key principles (based on the prevalent characterisation of AT by Kaptelinin 1996 and Nardi 1996b) provides a framework with which to consider the applicability of AT for analysing, in the following section, the awareness that users of systems develop through a process of interaction.

Principle I: Unity of Consciousness and Activity

Perhaps the most contentious principle of AT is the perspective that consciousness and activity cannot be meaningfully separated at both the individual and social level. The conscious action of an individual engaged in an activity is recognised by AT and it is held that a person inevitably possesses a number of biases based on personality, experience or training that will affect their actions. AT also contends that consciousness is a major determinant of human activity at the social level and that it is not simply a theoretical construct found in the head – consciousness cannot meaningfully exist without activity involving other people and artefacts. Instead, according to AT, consciousness exists in everyday practice and the 'social theory of consciousness' (Vygotsky 1978) is a fundamental principle of AT. It is an axiom of AT that tools mediate human consciousness and it follows that the introduction of new tools into an activity will affect both the social and individual processes that develop. A corollary of this is that the existing social processes of the community in which the activity takes place will affect the consciousness of the individual involved in the activity.

Principle II: Object-Orientedness

The term *object-orientedness* as used in AT should not be confused with the use of the same phrase in software engineering. In AT, object-orientedness refers to a perspective that the environment in which a person (subject) interacts plays an important role in their basic activities. Activity theorists contend that people are situated in environments which combine many different physical or abstract objects that influence how people act. Activity theorists consider social and cultural properties of the environment to be as important an object as physical ones. This principle contrasts sharply with the cognitive psychology approach and the human information processor model where human cognition is deemed to be based entirely upon low-level sensory functions. Object-orientedness however has much in common with the perception-action cycle espoused by Neisser (1976) where perception is deemed to be an active activity.

Principle III: Hierarchy of Activity

Many psychological theories use human action as the principal unit of analysis without considering the context within which these actions are situated. In AT the basic unit of analysis is the activity which is considered to be the *minimal meaningful context* required to understand situated actions. Consider for example the activity of providing airport services where there are many different specialists involved including air traffic controllers, operations managers and engineers. One operations sub-specialisation is provided by the Bird Control Unit (BCU) whose goal is to ensure that birds do not present a hazard to aircraft in the vicinity of the airfield. To achieve this goal, BCU staff drive around the airfield playing loud tape recordings of birds in distress to frighten other birds away. On their own, the actions of these people may seem irrational and even bizarre. However, viewed within the context of providing an airport service, the individual actions of the BCU become rational and can be understood. This is the *minimal meaningful context* required to understand the situated actions of the BCU.

A key principle in AT is the discrimination between a hierarchy of processes as shown in Table 4.1.

Process	Motivation	Relative Duration	Characteristics
Activity	Objective	Long	Minimal Meaningful Context for Actions
Action	Goal	Short	Planned and Conscious
Operation	Conditions	Short	Reactive and Automatic

Table 4.1 – Hierarchy of Activity

Table 4.1 shows that human activity is considered a relatively long-term process and activities are typically accomplished through shorter-term *actions* and *operations* involving different levels of awareness or consciousness. Participating in an activity requires a subject to perform conscious actions which have defined goals. In turn, actions require an individual to perform automatic operations that are triggered by certain environmental conditions. Typically, each conscious action is planned. With practice however, a conscious action can become an automatic operation. Conversely, an automatic operation can regress into a conscious action. For the remainder of this dissertation, changes in the hierarchy of activity will be depicted thus: Action→ Operation or Operation → Action.

Principle IV: Internalization/Externalization

Vygotsky (1978) asserted that human mental activity is derived from external action through a process of internalization. In AT, internalization is the transformation of external actions into internal mental processes. For example, people usually learn to count as an external action using their fingers; however, the activity of counting on their fingers is generally internalized into a process of mental arithmetic. Superficially, the principle of internalisation has much in common with the ubiquitous, but ill-defined ‘mental models’ in HCI studies which are purported to enable mental simulations to be performed before external action is taken (Kuutti 1996). Externalization is the opposite of internalization where mental processes manifest themselves as verifiable and observable behaviour. For example, checking the result of mental arithmetic using a calculator. This idea of internalization in AT is a powerful concept since it includes the notion of embodiment of knowledge and production of new knowledge that can be used in other contexts or activities.

Principle V: Mediation

Artefacts (both physical and abstract) often mediate human activity and the principle of mediation is a core concept in AT. The design of an artefact mediates the way that people can interact with the real world in the sense that it simultaneously limits and enables activity. An artefact also encapsulates the practices of its users through its physical properties and through the knowledge of how it should be used. An AT concept underlying artefact mediation is the formation of *functional organs* (Leontiev 1981) where an artefact’s physical and abstract properties and human abilities combine to produce a more effective system. In Figure 4.1, the tools, rules and the division of labour involved in an activity perform mediation. For the remainder of this dissertation, the two-way mediating relationship between, say the Subject and Tool, will be shown as Subject ←→ Tool.

Principle VI: Development

Finally, AT contends that unless it is understood how an activity developed into its existing form it cannot be fully understood. Vygotsky (1978) maintained that the actions of a subject cannot be comprehended from simply observing external behaviour; the motivation for the observed behaviour must also be understood as cognitive processes which cannot be inferred from observable behaviour. For example, it may be revealing to learn when and why particular conscious actions developed into automatic operations when undertaking a specific activity. The principle of development in AT concerns the analysis of the continuously evolving practice of an activity rather than taking a simplified snapshot of ‘fossilised’ behaviour at one particular instant.

These six principles can be used to constitute an integrated theory, and a systematic application of an AT approach must include the interaction between these principles. A common reply to the call for a richer understanding of human activity has been to complain that ‘human factors’ are too complicated to understand in context and consequently a reductionist view is adopted to decompose problems and enable experimental methods to be brought to bear. From this perspective it is often assumed that the mental processes that underpin human behaviour in the laboratory can later be extended to real-world activities. AT rejects this reductionist view and it provides a wider basis for studies that equally address the individual and social interactions, cultural factors and developmental aspects of human activity.

4.4 EVALUATING ACTIVITY-BASED AWARENESS

As noted in Chapter 3, there are several human-centred constructs that may lead to an understanding of these issues, an important one being the idea that people have an awareness of what is going on with respect to their interaction with the system and its environment. Finding ways of assessing and understanding the human activity involved in acquiring and maintaining SA is important in helping identify areas where users form incorrect awareness and where, as a result, there are interaction hazards.

Given the nature of this problem, AT is a strong theoretical candidate to provide an understanding of these 'Activity-Based Awareness' issues. If this is the case, AT-based analyses of the operation of such systems could help to inform the design of safety-related systems. What is required is a model of the SA process based on the principle that awareness is acquired through human activity. An SA Process Model based on the philosophy and principles of AT will now be introduced to demonstrate how AT and activity-based analyses may be brought to bear on the Situated Cognition perspective of SA in interactive systems.

4.4.1 An SA Process Model

In Chapter 3, a requirement was identified for the development of an SA Process Model based upon the four major SA themes of 'awareness', 'situated action', 'context' and 'dynamism' from the Situated Cognition perspective of SA described in section 3.2.4. These themes raise important issues which are used here to frame a model of the SA process shown in Figure 4.2.

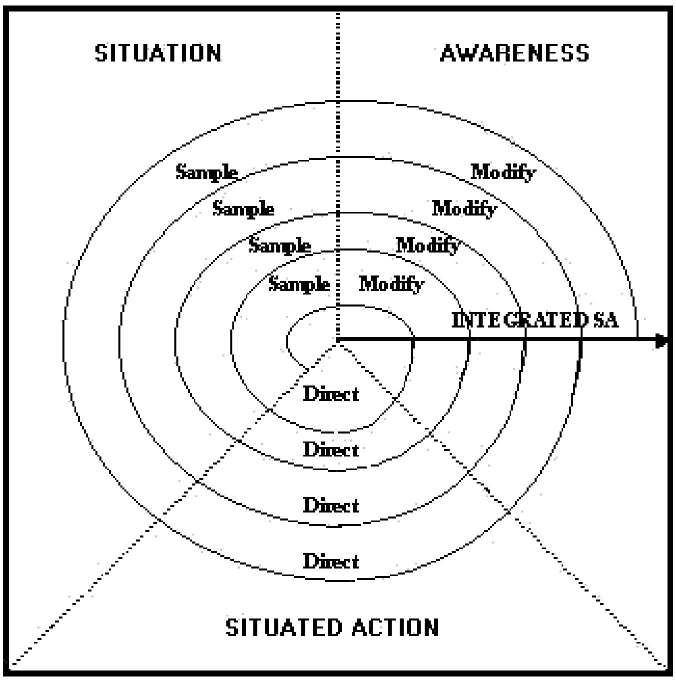

Figure 4.2 – An SA Process Model (adapted from Neisser 1976)

The SA Process Model encapsulates the human activity of proactive extraction (founded on the user's awareness), the significance of context (reflecting the situations in which an individual is acting) and the contribution of both of these areas to ‘situated action’ in SA.

The SA Process Model shown in Figure 4.2 is adapted from Neisser’s Perception-Action Cycle (1976) (shown in Figure 3.4) 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 individual’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 situational 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 individual’s receptivity to some elements of the available information. In contrast, Norman’s model does not expand on how information is perceived other than passively and therefore concerns itself only with the process of action.

In Figure 4.2, 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 individual begins to interact in their environment, they can be considered as moving along the spiral in the model from the central point. An individual may start anywhere in the cycle as, for example, a routine may take over to provoke initial action. Starting arbitrarily, the individual will *sample* the situation, building a perception of it by extracting and interpreting information content. This may lead the individual to *modify* their awareness, developing their subjective mental representation of the situation in which they are interacting. Changes in the individual'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 individual can be thought of as having passed through will have developed their awareness in a particular way. As time progresses the individual will cycle through these phases building an integrated awareness that grows with each iteration.

The SA Process Model is intended to capture the dynamic nature of human activity in the process of acquiring and maintaining awareness of a situation. It can be seen from the following discussion that the theoretical foundations of this model are consistent with the principles of AT introduced in section 4.3.2.

Principle I: Unity of Consciousness and Activity

The contribution of consciousness to the overall activity of proactive extraction is explicit in the SA Process Model which encapsulates consciousness based upon both internal cognitive and external social resources in the system environment. Thus, the model acknowledges the existence of social consciousness and also reflects the view that an individual’s awareness of an objective situation consciously effects the process of acquiring and interpreting new awareness in an continuous, proactive extraction cycle.

Principle II: Object-Orientedness

The model recognises the principle that many different physical or abstract objects are present as the objective situation is sampled to influence the modification of the subjective awareness held by the user. The subject’s consciousness then directs the sampling action to relevant objects in the situation based on their awareness and also on social and organisational factors which provide the objective for the activity and goals for individual actions.

Principle III: Hierarchy of Activity

At one level, the model represents the longer-term activity of acquiring and maintaining SA in a dynamic environment. The model also encapsulates the hierarchical aspect of this activity by subdividing the activity into the shorter-term actions and operations that are involved in the sample-modify-direct cycle. The model intentionally does not specify the activity level, and its associated level of consciousness (see Table 4.1), of these sub-activities as this will depend upon the context of the interaction.

Principle IV: Internalization/Externalization

The model directs the researcher to observe the process of acquiring and maintaining SA while encouraging the identification of what aspects of the external, situational objects become internalized as part of the subject's awareness. Analysis of the internalized information can indicate aspects where the information presented to the subject is deficient for acquiring appropriate levels of awareness. The externalisation of this awareness can be observed through the sampling strategy adopted.

Principle V: Mediation

The model synthesises aspects of the objective situation as presented to the participants and the awareness held by the subject. The objective situation may be presented to the subject through interaction with an artefact, such as a computer-based system, that simultaneously limits and enables the activity-based awareness. Thus the model encompasses the concept of tool mediation and the formation of a functional organ of machine and man through the interface. In the sense that SA is the fit between a subjective interpretation of a situation and the objective situation as represented by a tool (human-computer interface), the SA Process Model represents the mediating relationship between the subject and the artefact with which the subject is interacting.

Principle VI: Development

Finally, the model recognises that situational samples must be integrated with a current ‘picture’ to form an incremental, subjective awareness of a situation. This suggests the importance of analysing how a subject’s awareness is developed in order to fully understand the activity under observation. An analysis of the development of awareness should encompass both short-term adaptations to an environment and the longer-term, continuously evolving practice of an activity which influences a participant’s consciousness. This highlights the importance of understanding the immediate context of interaction and any longer-term organisational changes.

The structure of this model partitions different areas of interest which could allow researchers to concentrate on each as a distinct dimension contributing to awareness which can bring its own set of potential problems. The model should also enable a consideration of the boundaries between these partitions, which is possibly where many SA difficulties might arise. For example, as users integrate sampled information, the modification of their awareness may loosen the coupling between the operator’s subjective interpretation and the actual situation leading to a reduction in SA.

Having proposed a model for the evaluation of SA, it is also necessary to develop a method of applying the model to the analysis of complex, interactive systems and ultimately an evaluation of system safety. For theoretical coherence, a method that uses the SA Process Model as a tool must also be consistent with the principles of AT. The following section will outline a method for the analysis of the SA process and, after a discussion in section 4.4.3 of the *product* of SA, section 4.4.4 will give an explanation showing how the process analysis method can be used within an integrated evaluation of operator SA and ultimately system safety.

4.4.2 An SA Process Analysis Technique

An SA Process evaluation approach was developed using the six principles of AT as a guiding framework and drawing upon the SA Process Model as an analytical tool at appropriate points. This approach is presented in Figure 4.3 as a four-stage SA Process

Analysis Technique (SAPAT) and the individual stages are discussed in the remainder of this section.

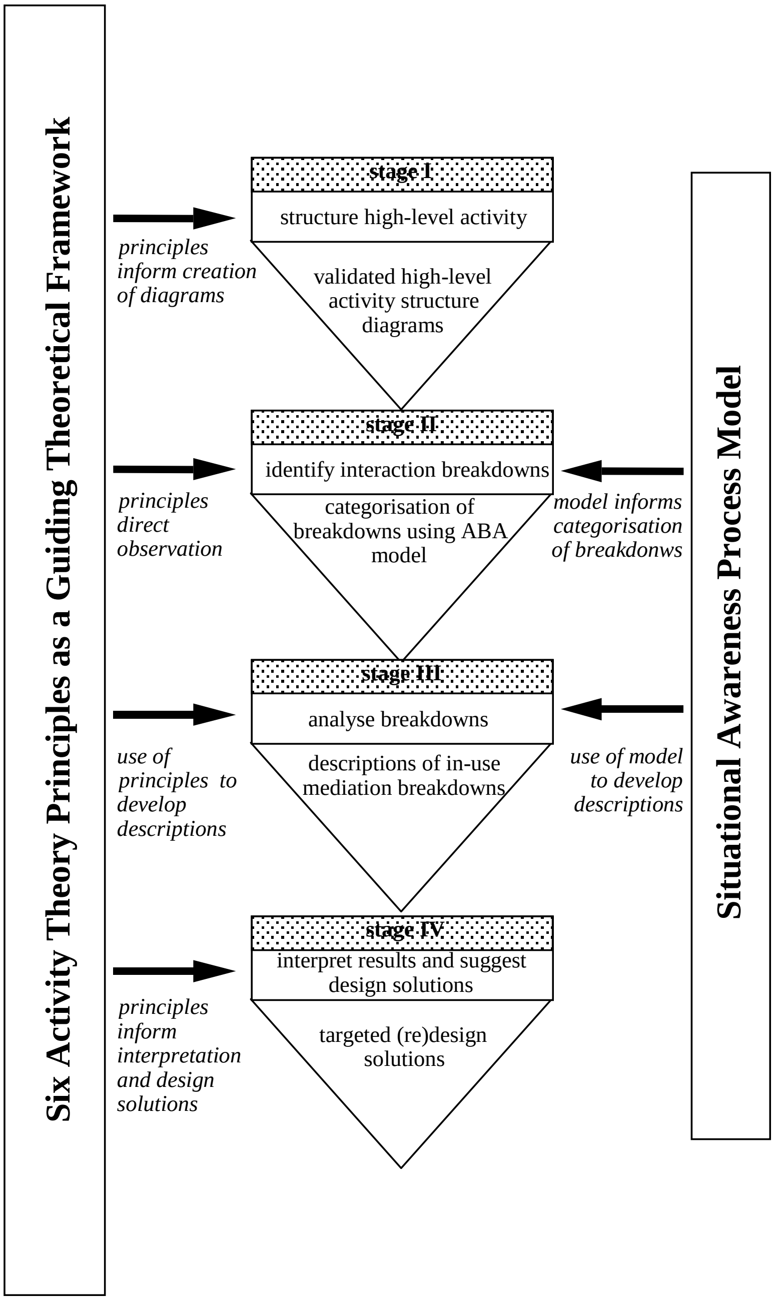

Figure 4.3 – Initial SA Process Analysis Technique (SAPAT)

Stage I: Structure High-Level Activity

The aim of this stage is to produce and validate high-level activity structure diagram(s) (as shown in Figure 4.3). The diagrams can then be used as a framework for categorising the initial data collected through, for example, interviews and questionnaires with domain experts.

Stage II: Identify Interaction Breakdowns

In this stage initial problem actions and operations resulting from interaction breakdowns are identified. Subject←→Computer←→Object mediation breakdowns can be identified and categorised using the SA Process Model and applying the principles of AT to direct the observation.

Stage III: Analyse Breakdowns using AT Principles

The aim of this stage is to analyse and describe the observed in-use mediation breakdowns using the SA Process Model and applying the AT principles as a guiding framework.

Stage IV: Interpret Results and Suggest Safe Design Solutions

In this final stage, the findings from the preceding stages are interpreted from an AT perspective (drawing on the AT principles). An understanding of the situated interaction breakdowns and their associated hazards will lead to informed re-design solutions which can be justified from a system safety perspective.

It has been argued in this dissertation that a integrated analysis of SA must support the evaluation of both the process of acquiring SA and the state of awareness that has the operator has acquired. Having proposed an SA Process Model in this section, it is now necessary to discuss the selection and adaptation of a technique for evaluating the *product* of SA acquired by a system operator.

4.4.3 An SA Product Assessment Technique

There are numerous SA Product assessment techniques available, however the discussion in section 3.3.2 suggested that the most suitable method for evaluating the state or product of SA would be a questionnaire-based evaluation technique. It was therefore anticipated that the product of SA could be evaluated using the relatively mature Situational Awareness Global Assessment Technique (SAGAT). However, it was considered necessary, from the perspective of this research, to adapt the technique to maintain consistency with the theoretical perspective of AT and the derived SA Process Model discussed in section 4.4.2 (this should not be surprising as a state of awareness can only be achieved through the process of interaction and the concepts are interrelated).

As noted in section 3.3.2, SAGAT is a technique developed by Endsley (1995c) for evaluating the state (product) of a subject's awareness of a situation. This technique is not well documented in the literature and Figure 4.4 shows the different SAGAT phases and their inputs. It can be seen from Figure 4.4 that a SAGAT simulation must be developed along with a suitable SAGAT question set. These outputs are then used during a SAGAT simulation to produce SA scores.

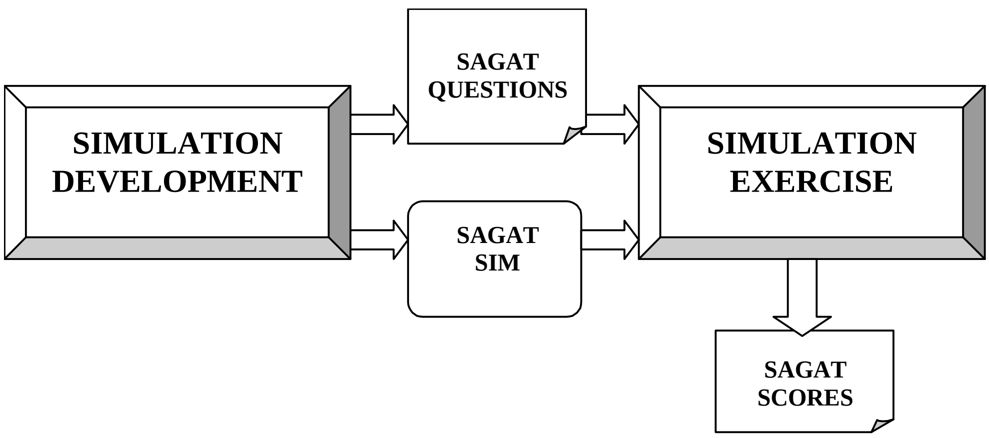

Figure 4.4 – SAGAT Phases

To overcome the limitations discussed above in section 3.3.1 regarding questionnaire-based techniques, SAGAT relies on freezing high-fidelity simulations at various intervals and administering SA-related questions. With this technique the system displays are blanked and the simulation is suspended while the subject answers questions about their current awareness of the situation. The answers are then compared with the real situation to provide an measure of SA. Figure 4.5 shows the setup of a SAGAT simulation.

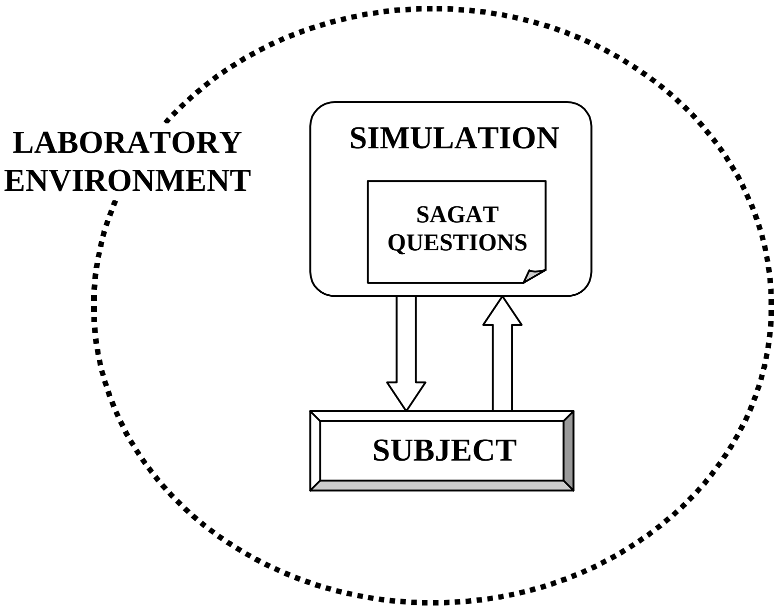

Figure 4.5 – SAGAT Simulation Setup

It is claimed that SAGAT is a global technique developed to assess SA across all of its elements based on a comprehensive assessment of operator SA requirements (Endsley 1995a). As a global measure, SAGAT should include questions about all SA requirements including Endsley's Level 1, 2 and 3 components discussed in section 3.2.2. This global approach has advantages over probe questions that cover only a limited number of SA items as subjects cannot anticipate the questions and modify their behaviour to increase their SA in a specific area. Endsley (1995a) has shown that the use of random sampling provides unbiased estimates of SA allowing SAGAT scores to be compared across trials, subjects and systems.

The primary disadvantage of the SAGAT technique, from the perspective of this research, is the lack of environmental context provided in the typical laboratory environment and the relative lack of simulation validity. Another methodological disadvantage is the temporary halt in the simulation. However, Endsley (1995a) has shown that this is not unacceptably intrusive and does not bias the results. She has also produced implementation recommendations for the best method of administering the SAGAT questions which can be summarised as:

- Subjects should be given an explanation of the SAGAT technique and trials should be conducted before the actual simulation is run.

- Subjects should be instructed to attend to their tasks normally with the SAGAT queries considered as secondary.

- A random selection from a constant set of questions is recommended at each freeze point to ensure statistical validity.

- The timing of each freeze should be unknown and unpredictable to the subject to prevent anticipation.

- No freeze should occur earlier than three minutes into a simulation to allow the subject to build up a picture and no two freezes should occur within one minute of each other. Stops should last a maximum of five minutes to minimise intrusiveness through short-term memory decay.

SAGAT has primarily been used within the confines of high to medium fidelity part-task simulations. For this research it was considered essential to conduct whole-task simulations using the actual equipment and environment to preserve the context faithfully. A detailed explanation of the application of a SAGAT-based technique as applied to this project is given in Chapter 6. However, it is appropriate at this point to discuss the major theoretical difference between Endsley's SAGAT and the variant of the technique used in this research project.

SAGAT is a global measure and it must include questions about all SA requirements. Using Endsley's model of SA (see Figure 3.2) this must include Level 1, 2 and 3 components addressing Perception, Comprehension and Projection processes respectively. This can be summarised by asking typical questions based upon what the subjects have seen, what they have understood and what they predict will happen. However, using the SA Process Model proposed in section 4.4.2 as a basis for the SAGAT questions, this *process* becomes Sample, Modify, Direct. This introduces one subtle difference between Endsley's version of SAGAT and the variant proposed here. With the variant, the Modify phase of SA acquisition will typically focus on both what the subjects have understood and what they predict will happen. The extra, Direct phase will focus SA questions on the situated actions related to the subject's SA sampling strategy. From a situated cognition perspective of SA, it is expected that this would provide vital SA information to reveal *what must be known* to update a subject's awareness when interacting within a dynamic environment.

4.4.4 An Interactive System Safety Analysis Method

Having presented a case for the suitability of SA Process Analysis Technique (SAPAT) and SA Global Assessment Technique (SAGAT) for the evaluation of SA, it follows that an integrated approach to the use of these methods would provide system designers with an method for the analysis of interactive system safety.

An initial outline of an Interactive System Safety Analysis Method (ISSAM) is presented in Table 4.2. It can be seen from Table 4.2 that both SAGAT and SAPAT activities can be conducted in parallel and that these very different SA evaluation methods are expected to produce data which would be useful to the other. For example, it is expected that the SAGAT freeze questions would be based upon the data SAPAT would produce during the initial system familiarisation stages of identifying and analysing interaction breakdowns.

System Safety Analysis Phase	Product Evaluation (SAGAT Phase - see Figure 4.5)	Process Evaluation (SAPAT Stage - see Figure 4.3)
1. System Familiarisation	Observation	1. Structure High -Level Activity 2. Identify Interaction Breakdowns 3. Analyse Interaction Breakdowns
	Informal Interviews	1. Structure High -Level Activity
	Questionnaire	1. Structure High -Level Activity
2. System Safety Evaluation	Develop Simulations	2. Identify Interaction Breakdowns 3. Analyse Interaction Breakdowns
	Conduct Simulations	2. Identify Interaction Breakdowns 3. Analyse Interaction Breakdowns
3. Safety Assessment	Derived Safety Metrics	4. HCI (Re)design Guidelines

Table 4.2 – Initial Interactive System Safety Analysis Method (ISSAM)

So far only the theoretical advantages of applying the principles of AT together with the SA Process Model and SAGAT to an analysis of safety in complex, interactive systems have been considered. Empirical evidence is required to enable an assessment of an integrated approach to the evaluation of SA and a suitable field-study is described in Chapter 5. ISSAM will be developed during the analysis of safety in the interactive system field study presented in Chapter 6 and an analysis of the data collected from the application of this method will be presented in Chapter 7. Based on this, a critique of the ISSAM method will be discussed in Chapter 8.

The field study focuses on the activity-based evaluation of an interactive system that relies on high levels of SA for safe operation, with the overall goal being to use the integrated SA evaluation approach to undertake analysis which would inform the quantitative safety assessment and (re)design of the system. It is anticipated that the general applicability of ISSAM to the analysis of situated interaction activity will addresses a major criticism in the literature that AT offers only abstract guidance to practitioners and that there are few practical methods for applying the principles of AT in real and complex technological work contexts (see for example Nardi 1996; Engeström 1987).

4.5 SUMMARY

This chapter has presented a case for using Activity Theory for the analysis of situated interaction hazards in safety-related systems. The chapter has explored the potential of Activity Theory, briefly introducing the theory and the key principles which it embodies. The chapter then briefly considered how Activity Theory might be used to gain an improved understanding of the use of complex, interactive systems and require some understanding of the cognition of users *in situ*.

An SA Process Model has been proposed in this chapter based upon the Situated Cognition perspective developed in Chapter 3. The chapter has also shown how the SA Process Model is founded upon the principles and philosophy of Activity Theory. The chapter has outlined an SA Process Analysis Technique (SAPAT) which uses both the SA Process Model (presented in Figure 4.2) and the principles of AT to analyse situated interaction hazards in context. The chapter also discussed the selection and adaptation of Endsley's (1995) Situation Awareness Global Assessment Technique (SAGAT) for evaluating the product of SA acquired by a system operator.

Finally, the chapter presented an initial proposal for an Interactive System Safety Analysis Method (ISSAM) which provides an integrated approach to the application of Activity Theory using the SA Process Analysis Technique together with SAGAT as an analytical framework for evaluating SA. The initial ISSAM proposed in this chapter will be developed through a field study of a complex, interactive system. The criteria for a suitable field study system this will be outlined in Chapter 5 and the chosen system will be introduced together with the expectations of the study. ISSAM will be developed during the analysis of safety in the interactive system field study presented in Chapter 6 and an analysis of the data collected from the application of this method will be presented in Chapter 7. Based on this, a critique of the ISSAM method will be discussed in Chapter 8.

Chapter 5

FIELD STUDY CRITERIA AND EXPECTATIONS

5.1 INTRODUCTION

In Chapter 4, an Interactive System Safety Analysis Method (ISSAM) was proposed to provide a framework within which interpretations can be made from a field study of a complex, interactive system. This chapter will now examine the criteria for a study of a suitable system that will enable the aim of this research to be achieved. The purpose of this is to minimize any bias that the researcher could bring to the interpretive element of the study by recognizing any assumptions or preconceptions before the field study commenced. An analysis of the data will be presented in Chapter 6 and any disparity between the expected outcome of the field study and the actual outcome will be evaluated in Chapter 7. The selection criteria for this field study was driven by the aim of this research which is to undertake an analysis of SA and to evaluate its link to safety in complex, interactive systems.

The chapter will begin by briefly examining both the organizational and technological selection criteria for an appropriate field study system. The chapter will then provide a general description of the organization and specific details of the complex, interactive system chosen as the focus for this research project together with a justification of its suitability. It is important to understand the context within which system operations are conducted and the chapter will provide a brief description of operations and the operational roles within the chosen system. The chapter will focus on a specific system operator role that relies heavily on SA for safe operation. The chapter will conclude with a discussion of the expectations of the field study and will give an outline of how the preconceptions of the researcher may affect the interpretation of the findings.

5.2 FIELD STUDY CRITERIA

The choice of a suitable organization and, specifically, a suitable safety-related interactive system was constrained by the aim of this research project. This research aims to undertake an analysis of SA and to evaluate its link to safety in complex, interactive systems. The question to address was therefore what attributes were required of a system that would be suitable for a field study of this nature.

Broadly, a suitable system could be characterised as one that requires the operators to interact within a complex, dynamic environment. The operator would typically rely on accurate SA for correct decision making and this awareness would be constructed through constant interaction with a human-computer interface that provides situational data. The implications of this are that an incorrect operator decision could result in a human error that may be potentially hazardous. Awareness-based errors such as these would be classified as knowledge-based mistakes as characterised by Reason (1991), and these could result in an incident or accident in a safety-related context.

The organisational context is also an important aspect of any research. Within the realistic constraints of resources available for any project, a researcher can normally choose to take either a broad but shallow or a deep but narrow approach to data collection. A deep but narrow approach was considered compatible with the aims of this research in order to provide a worthwhile contribution to the field. To enable a field study to be undertaken to a reasonable depth, it was therefore decided to select an application domain with which the researcher was familiar. It was realised that the benefit of this approach would have to be balanced against the potential disadvantages associated with maintaining objectivity when interpreting data collected during the field study.

Nonetheless, it was decided that the advantages of familiarity would outweigh the potential disadvantages, particularly when planning a complex field study at many diverse sites over a two year period of time. It is however, important to minimize any bias by recognizing any assumptions or preconceptions before the field study commenced and these will be discussed in this chapter. After an analysis of the field study is presented in Chapter 6, any disparities between the expected outcome of the field study and the actual outcome will be evaluated in Chapter 7.

From the previous discussion, it was decided that a suitable field-study would involve the Royal Air Force United Kingdom Air Defence organization and the remainder of this chapter will describe this organization and the specific complex, interactive system in detail.

5.3 A COMPLEX, INTERACTIVE SYSTEM DESCRIPTION

5.3.1 The United Kingdom Air Defence Ground Environment System [2]

The Royal Air Force (RAF) operates a variety of different Air Defence aircraft and ground-based equipment, which provides the means by which the mainland of the United Kingdom is defended. This research project will focus on the United Kingdom Air Defence Ground Environment (UKADGE) system which provides ground-based command and control services to military aircraft within the UK Air Defence Region (UKADR). In simple terms the UKADGE system is composed of two major elements: a means of detection and the weapons required to intercept unwanted intruders.

The UKADGE comprises ground-based command and control facilities, air defence radars, ground-to-air radios and other supporting systems. The system also interfaces with non-UKADGE agencies, comprising National Air Traffic Services (NATS) radars, the Flight Plan Dissemination System and other UK and Continental air defence systems.

The core capability of the UKADGE system is provided by the Air Traffic Control activity of Air Defence Fighter Controllers and also by the hardware and software of a system known as the Integrated Command and Control System which, together with data from other sources, can compile an air picture of the UK. The UKADGE system supports a dynamic air defence process involving a large number of hardware, software and human elements and it can therefore be characterised as a complex, interactive system as defined by Perrow (1984).

[2] Many new acronyms are introduced in this chapter and a Glossary of Terms can be found on page x.

5.3.2 UKADGE System Operational Elements

The UKADGE is a large, distributed command and control system with elements at diverse locations throughout the UK fulfilling the various executive, control and reporting functions. The operational elements of UKADGE are:

Combined Air Operations Centre (CAOC)

A single CAOC co-ordinates the air defence activity, monitors the state of the UKADGE command and control system and maintains its configuration at the optimum level to meet operational requirements.

Control and Reporting Centres (CRCs)

Two CRCs exercise tactical control of air defence assets. From these two centres, weapons systems are integrated to form the most effective reaction to a threat. Fighter aircraft are controlled during interception or general training missions. The CRCs are also responsible for the compilation of radar data from numerous sources into what is termed the Recognized Air Picture (RAP). The CRC is also responsible for the accuracy of some of the information in a distributed database known as the Resource Data Catalogue (RDC).

Remote Reporting Posts (RRPs)

A number of RRPs provide the operating environments, engineering and logistical support for those UKADGE radar sensors that are not co-located at a CRC.

In addition to these operational elements, UKADGE has support elements in the form of a System Maintenance Facility (SMF), an off-line software support facility, and the School of Fighter Control (SoFC) simulation facility. The locations of these UKADGE elements are shown in Figure 5.1.

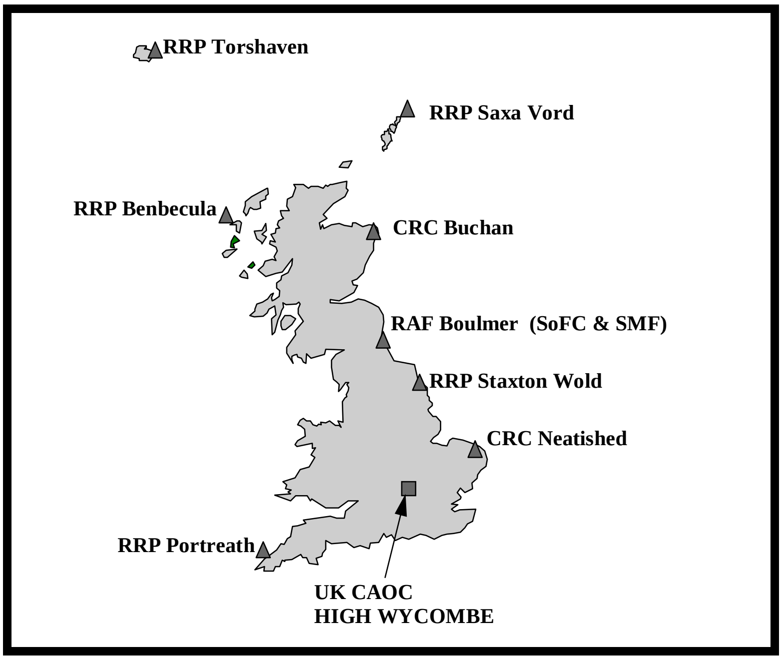

Figure 5.1 – Location of UKADGE Elements

If an element fails, provided at least one CRC remains available, the UKADGE resources will be automatically reconfigured to maintain an operational system. A manual reconfiguration capability is also provided to allow the system manager, based at the UK CAOC, to introduce and remove elements depending on the operational requirements.

5.3.3 UKADGE Major Sub-Systems

The UKADGE system includes a number of major sub-systems and a description of these follows:

UKADGE Radar Systems

UK military radar systems form an integral part of the UKADGE system and provide an essential source of situational data on both civil and military aircraft within the UKADR.

Tactical Data Links

Tactical data links and their associated data link buffers are merely radio communications systems providing secure communications for air defence situational information that cannot be accessed by other means.

Integrated Command and Control System (ICCS)

The ICCS provides facilities for all levels of management of air defence activity within the UKADR. It holds a comprehensive real-time database of all reported air and sea movements within the region, together with information on filed aircraft flight plans, available air defence resources and weather conditions. In addition, ICCS incorporates extensive voice communications capabilities including access to ground-ground and ground-air radio facilities.

The existing ICCS hardware is becoming obsolete and expensive to maintain and a project is underway to replace the system with more modern components. Many of the system changes will be transparent to the Fighter Controllers; however, a major tangible change will occur with the replacement of the existing ICCS interface which will impact significantly on system interactions and activities. The proposed changes to the system interface have been recognised as a major area of functional safety risk and a requirement for a method of assessing the relative safety of the replacement system has been identified (UCMP 1998).

Integrated Ground-to-Air Communications System (IGACS)

Ground-to-air radios providing voice communications with air defence aircraft can be accessed via the IGACS from any control console at any site around the UK. The availability of Ground-to-air radios is essential to the safety of the UKADGE systems; if the system fails the minimum safety requirement is to inform aircrew in all aircraft under control. It follows that IGACS interactions are considered safety-significant.

Flight Plan Dissemination System (FPDS)

The FPDS collates unclassified flight plan data from a range of sources which is then compiled into a master flight plan database accessible from dedicated terminals at UKADGE sites.

Defence Fixed Telecommunication System (DFTS)

The DFTS provides physical interconnectivity by means of bearer services for both voice and data communications between UKADGE sites.

An overview of these UKADGE major sub-systems and their logical interconnection is shown in the high-level system context diagram in Figure 5.2.

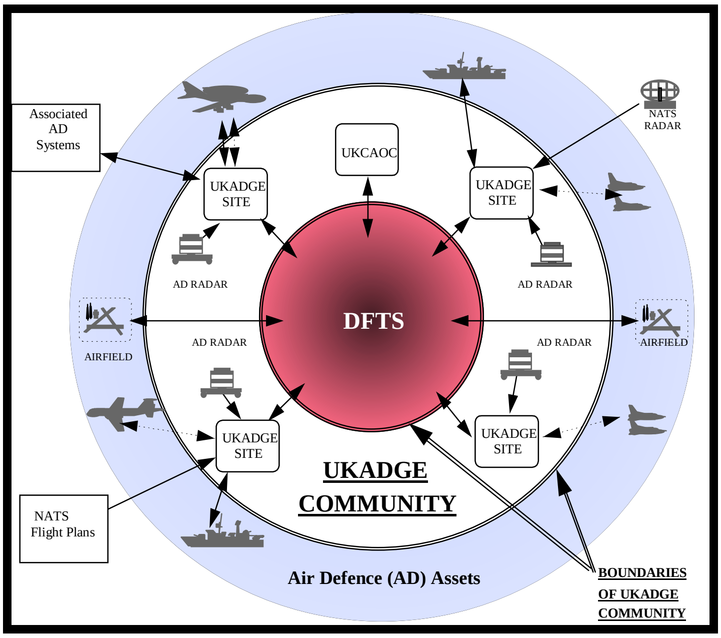

Figure 5.2 – UKADGE System Context Diagram

5.3.4 Integrated Command and Control System (ICCS)

The core UKADGE command and control function is provided by the ICCS, which maintains up-to-date tactical and strategic information on all matters related to both air and sea movements within the UKADR. The existing ICCS subsystems are described below:

Digital Data Network (DDN)

The DDN is a packet switched data network that connects the UKADGE elements together.

Data Handling System (DHS)

The DHS comprises main and standby processors with peripheral devices and engineering management facilities. The two functions of the DHS are merging aircraft plot data from different sources to form the situational picture, and compiling information on air defence resources into the Resource Data Catalogue (RDC).

Display and Voice Communications System (DVCS)

In the existing ICCS, the DVCS provides the operator interface, with access to the DHS and voice communications. The DVCS Universal Consoles provide limited functionality that includes the situational display and input to the DHS.

5.3.5 The ICCS Interface

The ICCS interface is made up of a number of components known collectively as the Universal Console (UC). The elements of the ICCS UC are shown in Figure 5.3 below:

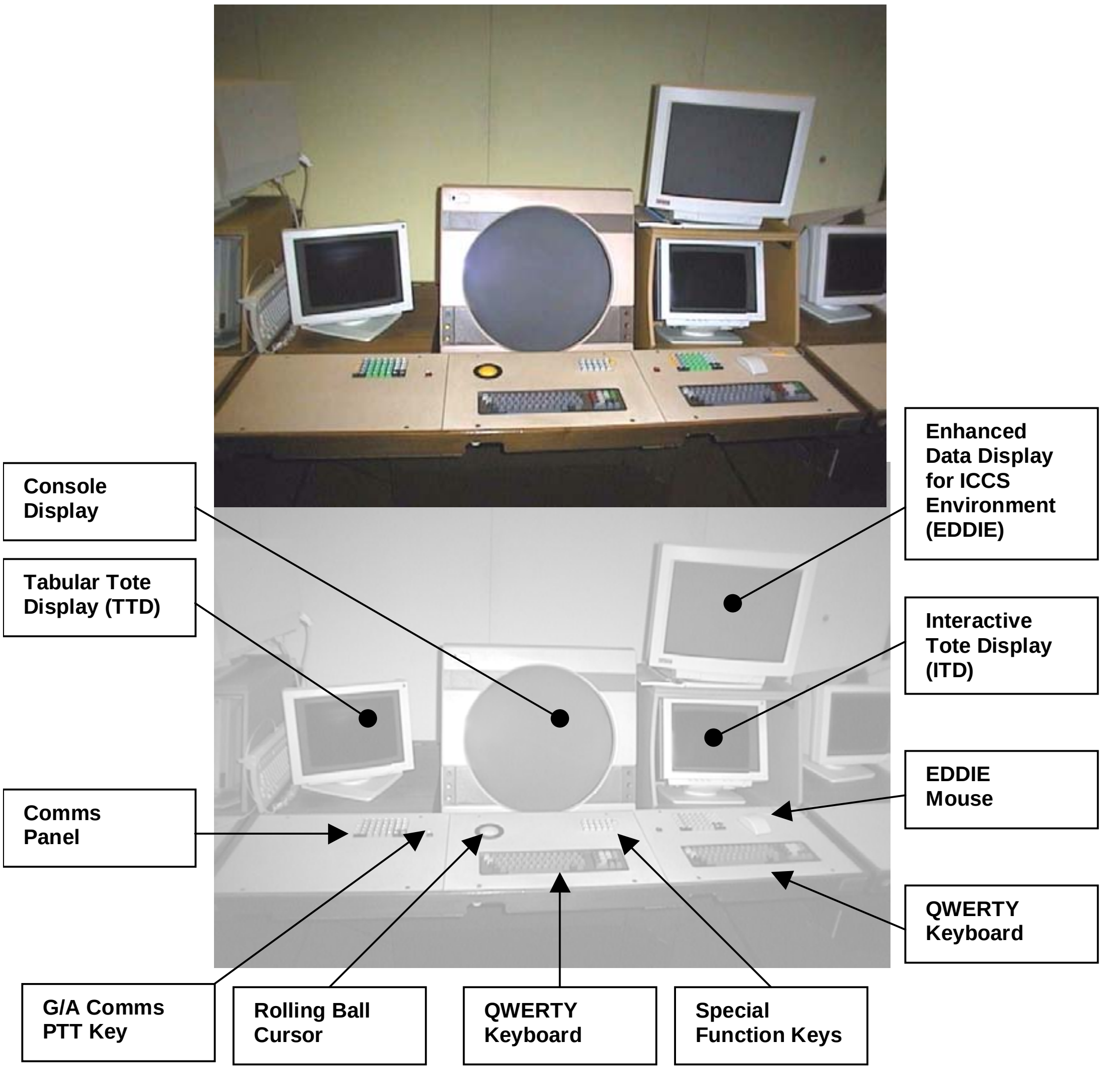

Figure 5.3 – The ICCS Universal Console

Many of the ICCS UC interface components will be referred to in the remainder of this dissertation therefore an explanation of the interface is required to gain an appreciation of the scope and type of operator interactions possible within the UKADGE system. The ICCS interface components are described as follows:

Console Display

The console display (sometimes referred to as the situational display) is the primary means of displaying the air picture to the UKADGE operators. This console displays static features such as maps and airfields and it also displays aircraft plots and tracks dynamically. Plots show actual aircraft positions while tracks show estimated aircraft positions and headings. It is possible for the operator to adjust the brightness and contrast of the console display.

Interactive/Tabular Tote Display (ITD/TTD)

The ITD and TTD provide the operator with the main means of viewing RDC information in a colour, text format only. For example, these displays routinely display information such as system alarms and alert messages. The ITD permits operator data inputs and outputs while the TTD is read only.

Communications Panel

The communications panel keys are used to access both ground-to-air (G/A) and ground-to-ground (G/G) communications facilities. The G/A communications keys will normally be linked to specific communications frequencies allocated to the controller for a specific mission using special function key switching sequences. The G/G communications keys can be used to access direct radio links with other controllers within the control room. Individual communications keys are illuminated when active.

G/A Communications PTT Key

The G/A communications Press-To-Talk key is used by the operator to toggle the aircraft communications transmitter channel on/off.

Rolling Ball Cursor

The rolling ball cursor is used to alter the position of the console display cursor.

Operator Keyboard

The main operator keyboard has a standard QWERTY layout keypad and a block of keys with functions specific to ICCS data input.

Special Function Keys

The special function keys are used to access functions relating directly to the configuration of the console display and the display of situational data. These keys are configurable and will enable access to different functions dependent upon the menu level and interaction context. Individual function keys are illuminated when active. The console displays a representation of the special functions keys and gives an indication of each key's current function. Typically, the operator will use these keys to configure their view of the situation through the interface and to access information on individual aircraft such as heights and headings and ranges.

Enhanced Data Display for ICCS Environment (EDDIE)

The EDDIE provides a colour graphics interface to present RDC information to the operators in the form of a Windows-type display. The UC must be explicitly configured by the operator to redirect either ITD or TTD information to the EDDIE display when required. Historically, this display was added some time after the original system was designed to address severe limitations associated with information presentation using the text mode ITD/TTD (see Hajost 1990 for a detailed explanation).

Mouse

The ICCS interface uses a standard two-button mouse to access and manipulate the RDC situational information displayed on the EDDIE. Unusually, a mouse mat is not provided.

5.3.6 UKADGE Operations Explained

Having provided an explanation of the technical equipment available to the operators, it is important to appreciate the organisational and procedural context within which UKADGE operations are conducted. This section will provide a description of Air Defence operations and an explanation of the major UKADGE operator roles.

The UKADGE system gathers situational data from many diverse sources. UKADGE radar systems provide radar information on aircraft movements, which forms the basis for the production of the air picture. This information is supported, whenever possible, by data from airborne early warning aircraft and naval vessels. A large-scale picture of air activity is provided via links to other European air defence systems such as the NATO Air Defence Ground Environment (NADGE) and Icelandic Air Defence System. The final major source of information is provided by NATS, which supply UKADGE with plot data from air traffic control radars and flight plan data. Recognised Air Picture (RAP) data comprises radar sensor data, track data and flight plan positions. The distributed database data (known as the RDC) includes airfield status, equipment status, system configuration, weather data, flight plans, and maps.

In simple terms, the UKADGE system is composed of two major elements: a means of detection and the weapons required to despatch unwanted intruders. The universal term used is ‘Control and Reporting’. Control refers to the control of weapons whereas Reporting refers to surveillance, detection and reporting of air tracks. There are many different specializations that contribute to UKADGE operations and many of these depend upon users having SA in context to achieve their individual and collective aims.

Within each CRC the operations rooms are physically divided between the Control Team and the Reporting Team. The Master Controller (MC) is in overall charge of the CRC and he will deal with both control and reporting matters. The MC is broadly responsible for ensuring that the environment within which the Control and Reporting Teams operate is conducive to efficient and safe operations. The division of labour within the UKADGE system is depicted in Figure 5.4 and a brief explanation of the specific contribution from each major specialisation is given in the following section. However, we will concentrate on the Weapons Controller (WC) as this role relies almost exclusively on the ICCS interface for the acquisition and maintenance of SA and it will therefore be the main focus of the field study.

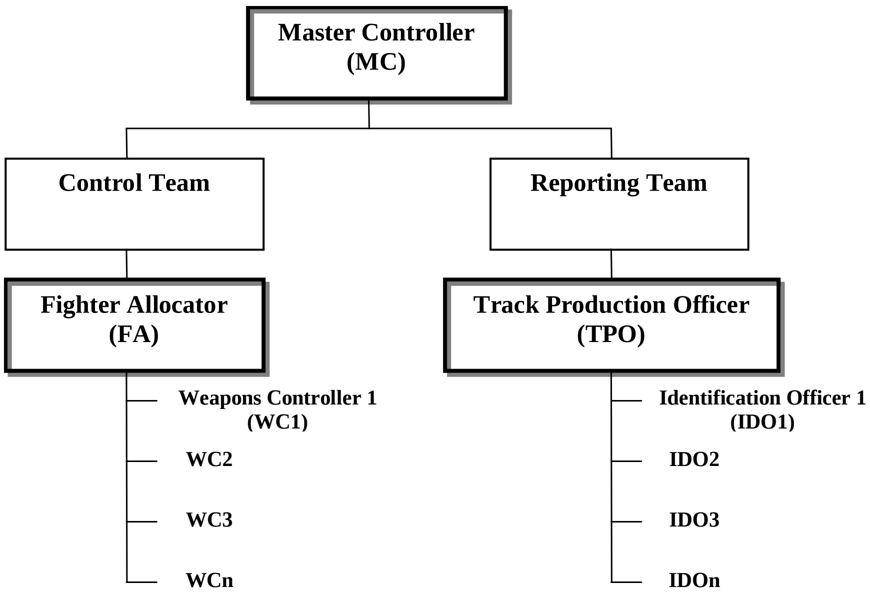

Figure 5.4 – UKADGE Operator Roles

The Reporting Team

Tracks detected by any of the AD or NATS radar sensors (see Figure 5.2) are given an identification category by an Identification Officer (IDO) based at one of the CRCs shown in Figure 5.1 above. The situational information upon which the IDO bases the identification comes from a variety of remote sources and the picture that results from the IDO's inputs is known universally as the Recognised Air Picture (RAP). The IDO can significantly affect the accuracy of the situational data and a mistake will present a credible but erroneous situation to the aircraft controller.

The Control Team

There are normally up to ten control positions available to the Control Team. The Fighter Allocator’s (FA) responsibilities include management of the flying programme and the allocation of areas to each sortie. The FA closely monitors the progress of the sorties and ensures that the Weapons Controllers (WC) do not deviate from their brief and that they maintain the required standards.

The primary UK Air Defence weapon is the Tornado F3 fighter aircraft. Although each fighter is equipped with a very capable radar, often complimented by data link information, they are unable to see the complete picture and rely on ground based Weapons Controllers (WC) to provide both tactical control and traffic deconfliction with other military and civilian aircraft. WCs almost exclusively use the ICCS interface to acquire and maintain their SA during operations. However, informal interactions (and specifically situational information exchanges) can occur with other control room staff.

The type of Air Defence sortie varies enormously. Most sorties involve three or four aircraft operating alternatively as interceptor and target. The air combat sorties are carried out within the Air Combat Manoeuvring Instrumentation (ACMI) range in the North Sea. Other types of sorties include high-level, low-level, supersonic, Air-to-Air refuelling and practice Air-to-Air radar jamming. In all these sorties, the task of the WC is to set up the participating aircraft in an area suitable for the sortie requirements and then provide tactical instructions during the execution whilst at the same time ensuring that the exercise is accomplished safely and clear of non-participating traffic. The role of the WC may be succinctly described as providing Air Defence pilots with enhanced SA. Clearly, to do this the WCs must themselves have accurate SA.

5.4 FIELD STUDY SUITABILITY

It is important to explain why the UKADGE organization, and more specifically the ICCS system, was initially deemed suitable for this field study. Firstly, it was recognised that the ICCS could certainly be characterised as a system that requires the operators to interact within a complex, dynamic environment which was identified as a selection criteria in Section 5.2. UKADGE operators typically rely on accurate SA for correct decision making and this awareness is built through constant interaction with a human-computer interface that provides situational data. Moreover, air defence operations are inherently safety-related as an accident involving either military or civil aircraft would be potentially catastrophic. This view is supported by Hajost (1990) who concluded that the task of the UKADGE air defence controller is complex due to a number of factors including the speed and capability of modern military aircraft, the vast quantity of data presented by the UKADGE sensors and the reduced time available to make safety-related decisions.

Secondly, the appropriateness of the UKADGE system for this research was demonstrated by a number of independent consultative reports including CGP (1994) and Roke Manor (1997). The CGP (1994) report was undertaken to determine critical decision making factors for UKADGE air defence controllers. The report concluded that the interface design is critical to timely and safe decision making and that the current ICCS interface design often turned operators into ‘keyboard operators’. Significantly, the report also concluded that a large proportion of the operators interviewed complained about the risk of loss of SA that occurs when accessing UKADGE system information and this was perceived to be due to a poor situational display.

Similarly, the Roke Manor (1997) study was initiated to carry out a task analysis of each different operational role within the UKADGE system. This study used various Human Factors techniques to collect quantitative and qualitative data relating to typical UKADGE operations and roles. Among the many conclusions from this report, it was recognised that SA was critical to safe UKADGE operations.

The final justification for focusing on this system came from the realisation that a research project of this potential magnitude would require a large degree of long-term support from the organization involved. It was determined that the greatest risk to the research programme would be that an organization would initially agree to cooperate until the demand on their resources became too large. What was required was an organization that could benefit tangibly from this research which was exactly the situation when the start of this research coincided with the initiation of the UKADGE Capability Maintenance Programme (UCMP).

The UCMP project was initiated to replace the ICCS system with more modern, commercial off-the-shelf components as the existing ICCS hardware is rapidly becoming obsolete and expensive to maintain. Many of the system changes will be transparent to the Fighter

Controllers; however, a major tangible change will occur with the replacement of the existing ICCS Universal Console interface which will impact significantly on system interactions and activities.

Despite all the previous arguments for the suitability of the UKADGE ICCS for this research, it was nevertheless decided that a pilot study would be undertaken as a risk reduction measure to confirm the initial expectations obtained from the documentary and anecdotal evidence. A detailed report of the pilot study findings can be found in Chapter 6.

5.5 PRECONCEPTIONS AND EXPECTATIONS

The researcher had a high degree of experience relating to the organization chosen for the field study based on twenty years experience in different Royal Air Force systems engineering environments including three years direct involvement with the UKADGE system. The implications of over familiarity were discussed briefly in section 5.2, however, this research focuses on the operational aspects of the UKADGE system pertaining to SA which were relatively unfamiliar to the researcher. It was expected that the researcher could remain objective when interpreting the observational aspects of the SA analysis. It was also expected that a high degree of familiarity would be an advantage given the relatively short period for orientation with the culture of the many diverse field study sites shown in Figure 5.1.

Nonetheless, it was recognised that the high degree of organisational familiarity would result in a number of preconceptions and, to minimize any resultant bias in the research, it was important that these were recognized before the field study commenced. In Chapter 2, it was argued that any comprehensive evaluation of SA must address the *process* of acquiring and maintaining SA and the *product* of SA itself. In the remainder of this section, the researcher's preconceptions will be discussed and related to the ISSAM analysis method proposed in order to outline what was expected from the case study. An analysis of the field study findings is presented in Chapter 6 and this is followed in Chapter 7 by a discussion on any differences between the expected outcome of the field study and the actual outcome.

5.5.1 Analysing Awareness with SAGAT

As discussed previously, the main UKADGE field study intended to use Endsley's (1995c) SAGAT to evaluate the quantitative levels of SA acquired by UKADGE WCs through interacting with ICCS. The SAGAT technique, and the variant used for this research has been explained in detail in Chapter 4.

It was expected that the application of SAGAT during the UKADGE field study would provide quantitative data which could be used to infer the level of SA support provided by the ICCS interface. In Chapter 2, it was argued that SA is vital in complex, interactive systems and it was therefore anticipated that the SAGAT data would provide a quantitative indication of the level of ICCS system safety.

It was not expected that any preconceptions would significantly affect the SAGAT evaluation as it was intended that the collected data would be entirely quantitative. It was also expected that the SAGAT question set would be difficult to develop given the researcher's lack of UKADGE operational experience; however it was anticipated that a domain expert could be used to develop objective questions which, with guidance, would be sufficiently global to address the ‘sample’, ‘modify’ and ‘direct’ phases of the SA Process Model proposed in Chapter 4.

WCs undertake a variety of extremely rigorous training courses and they are continuously assessed both formally and informally to qualify them to provide aircraft control services. The culture within the WC specialisation is generally very receptive to appraisal and honest self-assessment; it was therefore expected that the subjects would be motivated during the simulations and truthful when asked to answer SAGAT questions.

5.5.2 Analysing the SA Process

The UKADGE field study also intended to use the SA Process Model, together with the four stage SAPAT approach (proposed in Chapter 4) for investigating SA to evaluate the process that UKADGE WCs use to acquire and maintain SA through the ICCS interface.

It was expected that the application of an Activity-based approach to the analysis of the UKADGE system interactions would provide qualitative data which could be used to highlight SA acquisition and maintenance problems. It was also anticipated that the issues raised during ICCS interface analysis would lead to some general guidelines for the safe design of interactive systems for SA. In particular, it was expected that the observations during the field study would highlight the problems thought to be associated with interaction breakdowns and SA which were discussed in Chapter 2.

Again, it was not expected that any preconceptions would significantly affect the analysis and interpretation of SA data; although it was recognised that the subjective nature of the qualitative data collected would inevitably involve some bias. However, the operational environment was not initially well understood and a familiarisation period was required to orientate the researcher (see the Pilot Study findings in Chapter 6). If anything, it was expected that a domain expert would be needed to help to explain and interpret some of the field study observations given the complex nature of air defence operations.

5.6 SUMMARY

This chapter began by briefly examining both the organizational and technological criteria for the selection of an appropriate system upon which a field study could be based to achieve the aim of this research and, specifically, to further develop the Interactive System Safety Analysis Method (ISSAM) which was proposed in Chapter 4. Briefly, it was expected that a complex, interactive system would be suitable and it was also decided to select an application domain with which the researcher was familiar.

The system chosen for a field study was the UK Air Defence Ground Environment (UKADGE) system. This chapter presented a technical and organisational description of the UKADGE system which will provide the context for the detailed discussion of the field study activities and the findings in Chapters 6 and 7. The UKADGE system technical discussion included brief explanations of operational elements, major sub-systems, Integrated Command and Control System (ICCS) and the ICCS Interface components. The discussion on UKADGE system operations provided an explanation of the division of labour within the system including the Weapons Controller (WC) role which relies almost exclusively on the

ICCS interface for the acquisition and maintenance of SA. It was therefore decided that the WC role would be the main focus of the field study.

Based upon this system description, the chapter then presented a discussion of the suitability of the UKADGE system for this research. The discussion concluded that the UKADGE system fulfilled the selection criteria, nevertheless it was decided to undertake a pilot study to confirm the initial expectations obtained from the documentary and anecdotal evidence. A detailed report of the pilot study findings is presented in Chapter 6.

It was realised that the benefits of familiarity would have to be balanced against the potential disadvantages associated with maintaining objectivity when interpreting data collected during the field study. Therefore, the chapter finally provided a discussion of the expectations in order to recognise any assumptions or preconceptions before the field study commenced. Any disparity between the expected outcome of the field study discussed in this chapter and the actual outcome will be evaluated in Chapter 7 after the findings have been presented in Chapter 6.

Chapter 6

AN INTERACTIVE SYSTEM SAFETY STUDY

6.1 INTRODUCTION

This chapter will outline the structure and activities undertaken during both a pilot study and a main field study of the UKADGE system which was described in Chapter 5. This chapter will begin with a description of a pilot study which was undertaken initially to confirm the expected suitability of the UKADGE system for achieving the aim and objectives of this research. As well as confirming the suitability of the UKADGE system, another objective of the Pilot Study was to identify representative Air Defence Control scenarios that could be simulated during an interactive system safety study. The chapter will describe both the method and the findings of the Pilot Study, which covered the requirements of the ISSAM System Familiarisation Phase shown in Table 4.2.

Once the suitability of UKADGE was established through the Pilot Study, an interactive system safety study was then undertaken to evaluate interactive system safety through an analysis of both the process and product of SA using the Interactive System Safety Analysis Method (ISSAM) proposed in Chapter 4. This chapter will provide a detailed description of the UKADGE System Safety Study (USSS) conducted over a total period of 22 months and the specific activities undertaken for the individual Scenario Development and Simulation phases of the USSS. A detailed discussion concerning the analysis and interpretation of the data collected during the USSS will be presented in Chapter 7.

6.2 A PILOT STUDY

Notwithstanding the discussion in Chapter 5, concerning the suitability of the UKADGE system for this research project, a pilot study was undertaken primarily as a risk reduction measure. The initial aim of the Pilot Study was to confirm the expectation that the UKADGE system would fulfil the requirements for this research which is to undertake an analysis of a complex, interactive system where operator SA is a major safety factor. The secondary aim was to identify representative Air Defence control scenarios which could form the basis for the development of simulations for the USSS.

6.2.1 Pilot Study Method

All three UKADGE CRCs and the UK CAOC were visited during the Pilot Study to ensure that the findings would be representative of the entire UKADGE community and the views of Air Defence personnel from all branch specialisations were included. Data was collected from both semi-structured interviews and a questionnaire which was distributed to a representative sample of 17% of operational UKADGE personnel (77 from a total of approximately 459 operational personnel). This level of response was chosen as the representative sample population comprised only front-line operational personnel who were operationally competent in order to reflect the views of current Air Defence practice. The sample UKADGE population questioned during the Pilot Study is shown broken down by rank and specialisation in Table 6.1.

Key to Table 6.1 Specialisations

MC	**Master Controller**
WC	**Weapons Controller**
TPO	**Track Production Officer**
IDO	**Identification Officer**
FA	**Fighter Allocator**
Others	**Assistants**

RANK/SPECIALISATION	MC	WC	TPO	IDO	FA	Others	Totals
CIVILIAN INSTRUCTORS	1	2	1	1	2		**7**
SENIOR AIRCRAFTMAN						3	**3**
CORPORAL						1	**1**
SERGEANT		4					**4**
FLIGHT SERGEANT		1					**1**
PILOT OFFICER				1		2	**3**
FLYING OFFICER		2		1		4	**7**
FLIGHT LIEUTENANT	4	17	4	7	13		**45**
SQUADRON LEADER	2	2			2		**6**
Totals	**7**	**28**	**5**	**10**	**17**	**3**	**77**

Table 6.1 - Pilot Study Sample Population

The Pilot Study was undertaken by the researcher who was accompanied at all times by a qualified and competent WC who acted as a personal mentor throughout. This provided the researcher with an excellent introduction to the fighter control operational environment and an essential grounding in the culture of Air Defenders and Air Defence operations. The Pilot Study began at the School of Fighter Control (SoFC) and the Operations Centre at RAF Boulmer. The prevalence of students and the training environment enabled the collection of data from instructors and students of all ranks and experience levels. The Pilot Study then moved to CRC Neatishead which was planned to coincide with a major Air Defence Co-ordination exercise in order to maximise the potential number of survey participants and to allow the activities of a CRC to be observed during a busy operational period.

The initial data was collected using informal, semi-structured interviews to identify general opinions and trends and a questionnaire was then distributed to elicit more specific data from the subjects. The questionnaire was used specifically to identify a number of representative air traffic control activities (Air Defence missions) that would cover all different types of system interactions. A copy of the Pilot Study questionnaire is included at Appendix A. The questionnaire was also distributed to CRC Buchan and the resulting data was included in the Pilot Study findings. Questionnaires were distributed and completed independently and the recipients were given assurances of anonymity to encourage the expression of personal opinions and to minimise any possible bias due to peer group pressure.

6.2.2 Pilot Study Findings

The data collected from personal observation, informal and semi-formal interviews and the questionnaire were analysed and the advice of an Air Defence expert was sought for assistance with the interpretation of the data. The study was undertaken to confirm the suitability of the UKADGE system for developing the ISSAM introduced in Chapter 4 and, if necessary, the selection of suitable types of Air Defence missions that could be simulated during a main USSS. The findings relating to these issues are presented in the remainder of this section.

UKADGE System Suitability

Informal data collected during the Pilot Study confirmed the initial expectation that UKADGE is an interactive system which supports a complex, dynamic air defence process involving a large number of interacting hardware, software and human elements.[3] The study also confirmed that UKADGE operators typically rely on accurate SA for timely and accurate decision making. Observations, informal questioning and questionnaire data [4] also confirmed that the SA of a UKADGE operator is typically built through constant interaction with the ICCS interface which provides situational data from many different sources. It was significant that accurate operator SA was considered by all Air Defenders questioned to be the single most important safety criteria when controlling aircraft in busy UK airspace.

Simulation Scenarios

It is not important to understand the meaning of the different Air Defence sorties at this point; the purpose here is to explain *how* the simulation sorties were chosen to ensure that the maximum number of practicable interaction types would be covered during high-fidelity simulations. The Pilot Study questionnaire (Appendix A) asked the Fighter Controllers to categorise different Air Defence Sortie types as either High, Medium or Low workload. However, the practical application of this questionnaire showed that these categories were very subjective and therefore the data was simply summarised as shown in Table 6.2.

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[3] Informal notes taken during the Pilot Study were recorded in a notebook which is available for analysis.
[4] Completed questionnaires are available for analysis.

Table 6.2, shows clearly that Tanking, Air Combat Manoeuvring Instrumentation (ACMI) and 1 v 1 Bat & Ball operations were considered to be the ideal scenarios for evaluating UKADGE interactions during simulated control tasks. It was considered that these three scenarios would address the majority of possible operator interaction types during simulations.

SCENARIO	TOTAL
12 v 24 HVAAD	1
2 CAP Multi-Target Live Ex	1
High Flyer Supersonic	1
Area 4 RAS Intercepts	2
1 v 1 Low-Level Evasion	3
Coffee 'C'	3
4 Ship CAP Exercise	6
2 v 2 Split Frequency	7
Large COMAO Package	8
1 v 1 Bat & Ball	13
ACMI	20
Tanking	26
Total	**91**

Table 6.2 - Suitable Simulation Scenarios

The main USSS would ideally be based upon an analysis and evaluation of simulations of these three suggested control scenarios. However, it was advised by subject matter experts that only Tanking and 1v1 Bat & Ball should be chosen from the top three suggested scenarios; ACMI sorties were considered to be too complicated for high-fidelity simulation as they would require considerable manpower to control the dynamic simulation aspects due to the large number of aircraft involved. The Coffee 'C' sortie was identified as a suitable alternative and it was therefore decided to use this format in place of ACMI.

At this point in this dissertation, it is not important for the reader to have a detailed understanding of each control scenario chosen for the USSS simulations. Detailed descriptions of the Tanking, 1 v 1 Bat and Ball and Coffee ‘C’ sorties are given in Appendix B. However, to provide the reader with sufficient context for the remainder of this dissertation, the three chosen Air Defence Control scenarios are explained briefly below.

Tanking. Tanking involves usually one, but possibly more, tanker aircraft operating on an established racetrack within given height blocks within the bounds of a tanker refuelling area. Groups of fuel receivers, typically from two to eight aircraft per group, join with the tanker(s), under the control of a WC, to receive fuel. This operation frequently results in many aircraft squeezing into a relatively tight space, and the maintenance of safety becomes increasingly difficult as more aircraft join. The workload of the controller, and the interaction with the HCI, is increased during tanking sorties compared with routine training sorties.

1v1 Bat and Ball. The 1 v 1 Bat and Ball scenario involves three aircraft playing the interchanging roles of fighter, target and spare. The fighter is controlled against the target from a predetermined distance with the spare aircraft in a holding pattern. With good planning, once the fighter has completed its mission against the target, the correct distance has been achieved between the fighter/target pair and the spare. The target from this intercept now becomes the fighter for the next, and is controlled against the new target which was previously the spare; the fighter now becomes the spare and enters a holding pattern.

Coffee ‘C’. A Coffee ‘C’ sortie is typically used for groups of fighter aircraft to engage in air combat using electronic warfare that consists of communications and radar jamming. Controlling these engagements, particularly when eight or more aircraft are involved is invariably busy for the controller. There are three distinct ‘Takeover’, ‘Jamming’ and ‘Handover’ phases to these sorties, each of which presents its own challenge to the controller, which in turn increase the interaction with the interface.

It is useful here to summarise why the UKADGE system was deemed suitable for this research and why specific Air Defence Sorties were chosen. The Pilot Study confirmed the initial expectation that UKADGE is an interactive system which supports a complex, dynamic air defence process involving a large number of interacting hardware, software and human elements. It was also established that UKADGE operators rely on accurate SA for timely and accurate decision making and the SA of a UKADGE operator is typically built through constant interaction with the UKADGE system. A questionnaire was also used to identify a number of scenarios suitable for simulation during a main field study. Tanking, 1v1 Bat and Ball and ACMI sorties were considered ideal sorties for simulation. However, it was decided that it would be practical to replace the ACMI sortie with a Coffee 'C' due to simulation resource constraints. Significantly, operator SA was considered by all Air Defenders questioned to be the single most important safety criteria when controlling aircraft in busy UK airspace. Based on these findings, it was decided to undertake a main field study of interaction safety in order to fulfil the aim and objectives of this research project.

6.3 THE UKADGE SYSTEM SAFETY STUDY

An objective of this research is to undertake a field-study of a complex, interactive system to analyse and evaluate SA in context and to assess its contribution to system safety. As discussed in Chapter 3, an interactive system safety evaluation will require the quantification of SA which was identified as a critical safety attribute in the UKADGE system during the Pilot Study. The USSS was a significant study undertaken at four different UK sites over a period of 22 months between January 1998 and November 1999.

The main USSS was based predominantly upon simulations of the control scenarios identified in the Pilot Study for evaluating the UKADGE interactions including the ICCS interface. The USSS was undertaken in two distinct Scenario Development and Simulation phases, and together these covered the ISSAM data collection and analysis phases relating to the SAGAT and SAPAT activities. The Scenario Development and Simulation phases are described in detail below.

6.3.1 Scenario Development Phase

The Scenario Development phase comprised a number of distinct Video and Data Recording and Post-Video Interview sub-phases. The Video and Data Recording phase was expected to produce detailed data concerning live UKADGE sorties upon which subsequent high-fidelity SAGAT simulations could be based. The Post-Video Interview phase was expected to provide expert advice on the optimum SAGAT freeze points and specific SA questions. It was also envisaged that both the Video and Data Recording and the Post-Video Interview phases would facilitate an initial SA process analysis in accordance with SAPAT which was proposed in Chapter 4. A detailed explanation of these sub-phases follows:

Video and Data Recording

A Video and Data Recording phase was undertaken at CRC Neatishead for a period of two weeks to obtain data based on live UKADGE operations. The researcher was assisted by a film crew who produced professional quality video recordings of WCs and WC Assistants (WCAs) controlling live Air Defence sorties. Figure 6.1 shows how the video cameras were positioned in the operations room. One camera was directed at the ICCS Console Display to record the operational picture. Another camera was placed to provide a wide shot of the WC and WCA interacting with the entire system. A third camera was directed to provide a close shot of the WC's hands interacting with the ICCS interface. Sound recordings of both Ground/Ground and Ground/Air communications were dubbed onto the videos along with a recording of the informal communications within the operations room. The individual films were then edited to provide a single video showing all three shots together with the sound recordings in synchronisation.

Figure 6.1 - Scenario Video Setup

Ideally, it was intended that Tanking, 1v1 Bat & Ball and Coffee ‘C’ sorties would be filmed as identified in the Pilot Study. However, filming in an operational environment, with such a short period of available time was constrained by the operational commitments of the CRC which form its normal work and an opportunity to video a 1 v 1 Bat and Ball sortie did not arise. Consequently, a similar Air Defence control task was required to ensure that all interaction types were covered and domain experts advised that a 2 v 2 Split Frequency sortie should be chosen instead. A brief description of a 2 v 2 Split Frequency sortie follows.

> **2v2 Split Frequency.** The 2 v 2 Split Frequency scenario involves four aircraft undertaking air-to-air combat training in a predetermined control area. A different WC located at adjacent Universal Consoles in the same control room controls each fighter pair. As each fighter pair closes at distance with the opposing pair, the controller’s objective is to provide their aircrew with a tactical advantage by controlling the aircraft manoeuvres and providing situational data updates before they visually engage the opposing pair. A detailed description of a 2 v 2 Split Frequency sortie is given in Appendix B.

It was intended that SAGAT simulations would be developed based upon these Tanking, 2 v 2 Split Frequency and Coffee ‘C’ sorties. A detailed description of these sortie types is given in Appendix B. Transcriptions of the filmed sorties were produced from the videos and these provided the basis of the Post-Video Interview phase which is described below. Complete copies of transcriptions of these sorties can be found in Appendices C, D and E.

As well as the video recordings, data recordings of the filmed sorties were also produced to assist with the simulation development. An ICCS system data recording function is available to enable the production of complete mission recordings and allowing a mission to be replayed for analysis purposes at a later date. It was intended that both SAGAT simulations and SAPAT analyses would be based upon the video and data recordings to maximise the simulation fidelity. It was expected that an analysis of the video recordings would provide information on suitable SAGAT freeze points and the production of SAGAT questions as well as SAPAT interaction data. It was also anticipated that the live data recordings would be used to provide the ‘background’ aircraft traffic for the SAGAT simulations to preserve the original environmental context.

Post-Video Interview

Post-Video interviews and video analyses were carried out during an interview with the WC and WCA involved in each sortie. A copy of the Post-Video Interview guide can be found in Appendix F. The interviews and video analyses took between two to three hours and the aim was to collect SAGAT and SAPAT data on the subjects themselves and the filmed Air Defence sorties. The semi-formal interviews were structured as follows:

Introduction. An introduction was given to the aim of the USSS to provide the subjects with some motivation for the questioning and to set the overall context of the interview.

Personal Details. The personal details of each subject, including a brief summary of UKADGE experience, were gathered.

Video Analysis. The video analysis phase was used to facilitate the collection of data on the Air Defence sorties which would assist with the production of SAGAT simulations and also provide SAPAT data. The video analysis was undertaken firstly to identify and probe critical interaction points for each sortie. Critical interaction points were defined as those points in a sortie when the controller makes decisions based entirely upon their awareness of the situation. Safety-significant interaction points were characterised as high workload points in a sortie where high SA is required and the WC makes critical decisions. It was intended that the identified critical interaction points would be used as SAGAT freeze points while the probe questions would reveal SA requirements that would form the basis of the SAGAT questions at each freeze point. The video analysis was also undertaken to facilitate the initial SAPAT analysis. Specifically, the videos were used to Structure High-Level (Air Defence) Activity and to Identify any Interaction Breakdowns as discussed in sections 4.3.1 and 4.4.2 respectively.

Awareness Assessment. An awareness assessment was undertaken to collect data on the subject's own perception of SA. A questionnaire was used to elicit general data on individual perceptions of SA, usability and safety.

Debrief. Finally, the subjects were given an opportunity to ask any questions or add any extra information deemed relevant to the study.

6.3.2 Simulation Phase

The Simulation phase comprised a number of distinct Simulation Production, Simulation Exercise and Post-Simulation Interview sub-phases. The Simulation Production phase was expected to produce high-fidelity SAGAT simulations based upon the data collected during the Scenario Development phase of the USSS. It was expected that the Simulation Exercise phase would produce SAGAT data and facilitate further SA process analysis in accordance with SAPAT which was proposed in Chapter 4. Finally, it was anticipated that the Post-Simulation Interview sub-phase would produce additional qualitative data relating to both observations and SAGAT scores derived during the SAGAT simulation runs. A detailed explanation of these sub-phases follows:

Simulation Production

The researcher was assisted by the UKADGE Exercise Production Section and an Air Defence Expert to develop three SAGAT simulations based upon the findings of the Scenario Development phase. Specifically, three high-fidelity field study simulations were produced based on Tanking, 2v2 Split Frequency and Coffee ‘C’ Air Defence control sorties. The focus of this research is on safety and Chapter 2 discussed the need to ensure that system interactions are designed to accommodate emergency situations when safety is an issue, therefore the SAGAT freeze points coincided with the critical interaction points identified during the Video and Data Recording phase. The data recording tapes were also used to produce realistic background aircraft traffic and thus preserve the original environmental context.

The simulations took approximately three months to develop between December 1998 and February 1999 and each simulation required the production of the following items:

- An ICCS simulation tape based upon the representative UKADGE control sorties identified in the Pilot Study and developed further during the Scenario Development phase. These tapes provided all the ITD and TTD tote data relevant to a sortie giving, for example, the various airfield weather states. The simulation tapes also provided all the ‘background’ aircraft plots for display on the UC.

- A script for the simulation team giving precise details of the timings for the initiation of real-time simulation events in relation to the simulation tape (see Appendices G, H and I). For example, the precise timing must be given for the real-time initiation of the aircraft which are to be ‘controlled’ by the WC during the simulation.

- A SAGAT question set comprising of five freeze points each having six SA-based questions (see Appendices J, K and L). These questions were initially very difficult to produce and required the expert opinion of a qualified WC to decide what situational elements were relevant to safety at each SAGAT freeze point. A detailed discussion on the development of the UKADGE SAGAT question set is given in Chapter 8 when a critique of SAGAT is presented.

Simulation Exercise

SAGAT simulations based on the Tanking and 2v2 Split Frequency scenarios were run at CRC Buchan during the period 15 - 26 March 1999. Contrary to expectations, this period was not long enough for all the simulations to be run as a number of initial practice runs were required to refine the simulations and the SAGAT questions relating to each freeze point and also to train the Exercise Control Team. The remaining Coffee ‘C’ SAGAT simulations were therefore run at RAF Boulmer during the period 12 - 14 July 1999.

When conducting the SAGAT simulations it was considered essential that all attributes were controlled apart from the specific variable of interest (in this case it was SA) to ensure the validity of the results. Also, to use the SAGAT data for a comparison of system safety it was considered essential to ensure that a similar sample population is used to remove any bias introduced through individual WC characteristics. The USSS ran a total of 21 simulations using a sample population of WCs with the characteristics shown in Table 6.3.

SUBJECT (T=Tanking V=2v2 C=Coffee)	RANK	UKADGE ROLE	AGE	GENDER	YEARS IN AIR DEFENCE
T1	Sgt	WC	32	M	8
T2	Flt Lt	WC	27	M	4
T3	FS	WC	38	M	7
T4	WO	WC	42	M	14
T5	F/O	WC	25	M	2
T6	Flt Lt	SoFC	28	M	6
T7	Lt	RN FA	26	M	5
V1	F/O	WC	25	M	2
V2	FS	WC	38	M	7
V3	Flt Lt	WC	28	M	6
V4	Flt Lt	1ACC	29	M	6
V5	Flt Lt	WC	29	M	4
V6	Lt	RN FA	26	M	5
V7	Flt Lt	WC	30	M	7
C1	Flt Lt	WC	27	M	3.5
C2	Sqn Ldr	MC	40	M	15
C3	FS	WC	38	F	7.5
C4	Flt Lt	WC	32	M	10
C5	F/O	SoFC	24	M	4.5
C6	Flt Lt	MC	38	M	17
C7	F/O	SoFC	25	M	3.5

Table 6.3 - Field Study Sample Population

The SAGAT simulations used a number of different WC/WCA pairs during each simulation run to ensure that derived data was independent of individual characteristics. The simulations required an Exercise Control Team which comprised four people in total; one Exercise Administrator (EA), one Exercise Controller (EC) and two Trace Drivers (TDs). The simulations were conducted using both upper and lower operations rooms to prevent the subjects from listening to the instructions passed between the Exercise Control Team thus maintaining realism. The EC and TDs were situated in the upper operations room while the EA, WC and WCA operated from the lower operations room. The field study simulation set-up and the interactions between those involved are depicted in Figure 6.2 which shows both the control and information flows between the WC, WCA and the Exercise Control Team.

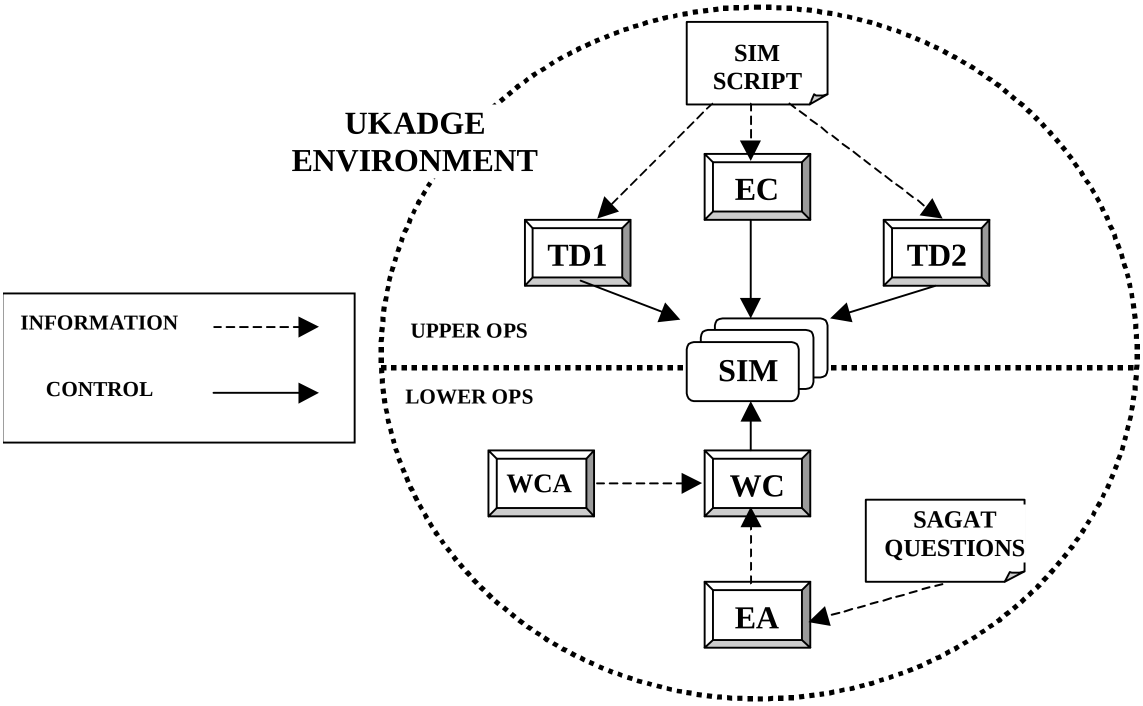


Figure 6.2 - Field Study Simulation Set-up

The members of the Exercise Control Team carried out the following specific functions:

Exercise Administrator (EA)

The EA was situated on an ICCS console adjacent to the WC/WCA. The EA was in constant communication with the EC via normal Ground-Ground voice communications to monitor the progress of the simulation. The EA could also monitor all simulated Ground-Ground and

Ground-Air voice communications. The main function of the EA was to stop the WC and ask the six relevant SAGAT questions and to note the answers given at each pre-designated simulation freeze point. The EA would then instruct the EC to recommence the simulation after each freeze point.

Trace Drivers (TDs)

The TDs were used to simulate the actions of the simulation aircrew by ‘driving’ the aircraft plots around the ICCS console in real-time as instructed by the WC. The TDs also communicated with the WC using normal Ground-Air voice communications channels and procedures to simulate exactly the operational radio communications between aircrew and controller.

Exercise Controller (EC)

The primary role of the EC was to initiate simulation events and to co-ordinate the actions of the two TDs to ensure that the simulation scripts were followed faithfully thus enabling each simulation to be repeated exactly. The EC was a qualified and competent WC and was required to act as an FA to provide the subject WC with an initial sortie briefing as required during ‘real’ operations. During the simulation, the EC also acted as all external agencies (for example a civilian air traffic controller during aircraft handover or takeover). The EC communicated with the WC using normal Ground-Ground Voice communications channels and procedures. The EC also initiated changes to the situational data displayed on the ICCS totes.

Post-Simulation Interview

Following each simulation, a debrief was conducted with the WC concerned in order to probe both the observations made during the simulations and to examine possible explanations for the SAGAT scores during each run. In particular, the interview questions focused on those SAGAT questions that were answered incorrectly during the simulation and the subjects were asked to provide explanations. A copy of the Post-Simulation Interview guide is presented in Appendix M.

6.5 SUMMARY

This chapter has described the activities undertaken during a Pilot Study and a main field study of the UKADGE system which were described in Chapter 5. The chapter began with a description of the Pilot Study which was undertaken primarily to confirm the expected suitability of the UKADGE system for achieving the aim and objectives of this research. After the suitability of UKADGE was confirmed, the Pilot Study identified representative Air Defence Control scenarios that were simulated during the main system safety study.

A main safety study was undertaken to evaluate interactive system safety through an analysis of both the process and product of SA in this safety-related system. An examination of the theory underlying any evaluation of SA was given in Chapter 3 and the conclusions from this discussion provided a framework for the conduct of the field study activities. The current chapter has provided a detailed description of the UKADGE System Safety Study (USSS) and the specific activities undertaken for the individual scenario development and simulation phases. A detailed discussion of the interpretation of the findings from this field study will be considered in Chapter 7.

The USSS was a significant study undertaken at four different UK sites over a period of 22 months between January 1998 and November 1999. The USSS was undertaken to provide benchmark data and a method for the evaluation of the relative safety of the ICCS interface. To derive benchmark safety data an analysis of the ICCS interface was undertaken in two distinct Scenario Development and Simulation phases. Video recordings of live Tanking, 2 v 2 Split Frequency and Coffee ‘C’ sorties were developed. Simulations were then developed for the ICCS system based upon the live video recordings. 21 simulations were run at operational CRCs during which WCs were asked to answer pre-scripted questions at pre-designated simulation freeze points.

Chapter 7

DATA ANALYSIS AND INITIAL INTERPRETATION

7.1 INTRODUCTION

In Chapter 6, the activities undertaken during a safety analysis of a complex, interactive system were described. Having explained what was done to collect the field study data, this chapter will explain how the ISSAM approach to interaction analysis proposed in Chapter 4 was used to analyse and interpret the data. The chapter will outline what SA process and product-related data were collected and how these data were organised before offering an initial interpretation of the data. This chapter covers the requirements of the initial ISSAM Data Collection and Analysis phase shown in Table 4.2.

The chapter will begin with an examination of the SA process-related data collected through the application of SAPAT. The chapter will then examine the SA product-related data collected during the SAGAT simulations which were conducted at various UKADGE sites. Before the data is interpreted, the chapter presents a discussion on any disparities between the expectations of the studies outlined in Chapter 5 and the actual findings. An initial interpretation of the SAPAT and SAGAT data is then presented using insights from the Activity Theory principles which were presented in Chapter 4.

Attention will be drawn to those specific areas of this chapter where the interactive system safety analysis data collection techniques were found to be problematical, incomplete or impractical. This chapter will explain how additional data was derived using modifications to ISSAM and the chapter will briefly explain what modifications were made to the original safety analysis method proposed in Chapter 4. However, a complete appraisal of ISSAM will be given in Chapter 8, including a detailed explanation for any modifications that were required to the original method resulting from the practical application of the method during the USSS.

7.2 PROCESS-RELATED DATA

7.2.1 SAPAT Data Analysis

The SA process-related data was collected during the USSS through the application of SAPAT described in Chapter 4. The data was analysed and organised in accordance with the three SAPAT stages namely: Structure High-Level Activity, Identify Interaction Breakdowns and Analyse Interaction Breakdowns. A definition of an interaction breakdown was given in Chapter 2, however as a reminder, an interaction breakdown can occur when human-computer communication is interrupted for example, when a system behaves differently than was anticipated by the user. Interaction breakdowns can be explained in AT terms as a developmental change from Operation → Action and can trigger an inappropriate action or fail to trigger an appropriate action at all. Generally, interaction breakdowns can only be identified and interpreted by a knowledgeable observer *in situ*. An explanation of how the USSS data were analysed in accordance with the three SAPAT stages will be given in the remainder of this section.

SAPAT Stage 1 - Structure High-Level Activity

This data collection stage produced and validated the structure of the high-level activity undertaken by the UKADGE WCs during: the conduct of live Air Defence operations, the production of the SAGAT videos and during the SAGAT simulation exercises. The aim of this stage was to focus on the structure of Air Defence as an activity, and a high-level activity diagram (shown in Figure 7.1) was therefore constructed and validated with assistance from numerous Fighter Controllers. The Air Defence Activity Structure diagram in Figure 7.1 was used as a framework for categorising the initial data collected through the semi-formal interviews and questionnaires with domain experts during the Pilot Study described in Chapter 6.

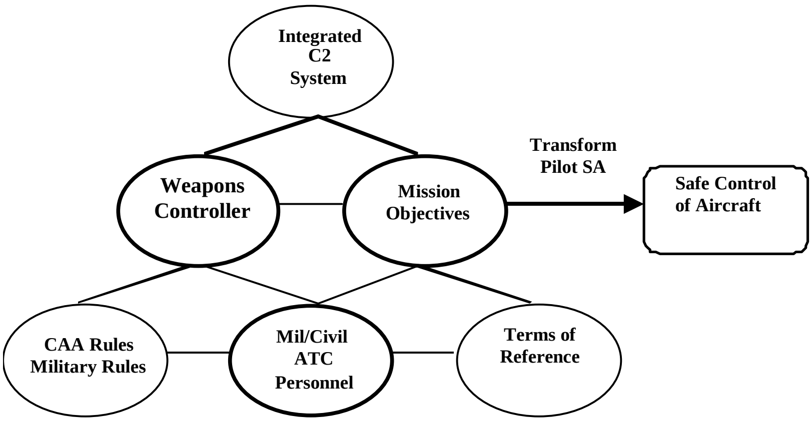


Figure 7.1 – Air Defence Activity Structure

Informal notes were taken of observations and subsequent video analyses were carried out of Fighter Controller activity during a number of representative Air Defence missions.[5] The observations and subsequent questions during post-video interviews (see Appendix F for interview guide) again confirmed the expectation that SA in Air Defence (in the sense of a coupling between an objective situation and the subjective awareness of the operator) is acquired and maintained through individual and social activity. It was also established through questioning the WCs that the objective of achieving a safe sortie is fulfilled by the process of transforming (updating) the SA of the pilots under Air Defence control.

However, from an analysis of the videos and transcriptions (Appendices C, D and E) it was apparent that the high-level activity diagram in Figure 7.1 could not provide sufficient detail to structure an analysis of the mediating properties of the elements contributing to the Air Defence activity. This is because the activity structure diagram does not show how the functionality (or lack of functionality) of the UKADGE system can affect the interactive process of acquiring and maintaining SA. This is a general characteristic of an activity structure diagram which depicts only those elements involved in an activity without providing any detail on the nature of the mediating relationships involved. For example, Figure 7.1 shows that a WC’s activity is mediated by other Air Defence personnel, however it does not show in detail *how* this mediation can affect a WC’s SA.

[5] Informal notes and videos are available for analysis.

This research is primarily interested in developing an understanding of the mediating properties of UKADGE system interactions including the ICCS interface and the subsequent effect that this can have upon the WC's awareness. While the structure of the high-level Air Defence activity was being analysed, it became apparent that a description of the UKADGE system functionality in terms of the interactions between the WC and the available *sources* of situational data was missing from the initial ISSAM proposal.

It was decided that a system model such as this was required to enable a Preliminary Hazard Identification (PHI) to be undertaken to consider SA-related interactions from the WC's perspective and to identify those which are hazardous. It is clearly not practical to analyse all system interactions, therefore a PHI was undertaken to focus the field study analysis on the hazardous system interactions which are safety-related as these are the main focus of this research.

It was therefore deemed necessary to develop a representation of the UKADGE system that uses the SA Process Model to represent the human factor from the WC's perspective and depicting the possible interactions with the sources of situational data. A UKADGE SA Interaction Model was developed (shown in Figure 7.2) to enable a complete system safety analysis (technical and human factors contributing to the operator's SA) of the UKADGE system interactions.[6] The UKADGE SA Interaction Model was validated by numerous, experienced UKADGE operators during the preliminary stages of the USSS.

Figure 7.2 shows a high-level functional model of the UKADGE system in terms of its primary safety function of providing SA data and, perhaps more importantly for this research, the tightly-coupled (as defined by Perrow 1984) SA-related interactions between the WC and the interactive system. The UKADGE system is divided into three major SA-related interactive areas showing the Communications, Display and Reporting Team interactions from the WC's perspective.

[6] The author acknowledges the intellectual input of Squadron Leader James Savage in developing this UKADGE SA Interaction Model.

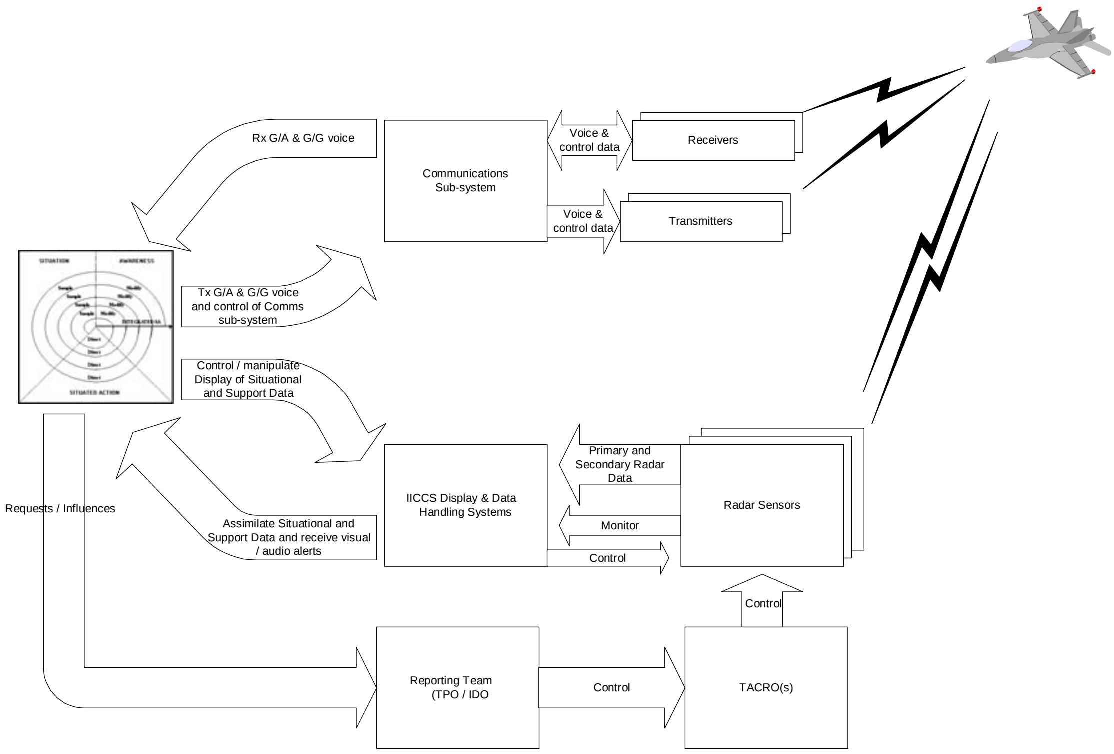


Figure 7.2 - UKADGE SA Interaction Model

Figure 7.2 introduces one new term relating to the conduct of Air Defence operations which were explained in section 5.3.6. The USSS data analysis showed that the WC's radar sensor situational data can be significantly affected by the TACtical Radar Operator (TACRO) who can make numerous adjustments to the radar's signal processing electronics. The TPO can directly request adjustments or the TACRO will often make adjustments when it is deemed necessary. In terms of the SA data presented to the WC, the TACRO's adjustments have the potential to filter out significant situational data.

The UKADGE SA Interaction Model shows the complete (human and technical) system functionality in terms of SA and a discussion will be presented in Chapter 8 to show how this UKADGE specific model can be made generic for the analysis of other complex, interactive systems as part of the ISSAM proposed in Chapter 4. It can be seen from this system model that the operator's SA will not only depend upon the sampling strategy applied by the operator to the available situational data; but that it also depends upon the correct functioning of other system, human and technical elements to provide accurate and timely situational data in the first instance. As described in Chapter 4, the SA Process Model was used to identify and analyse the hazards associated with the SA 'extraction' process through the WC's interaction with the system.

The UKADGE SA Interaction Model in Figure 7.2 shows the sources of the WC's situational data and this was used during the USSS to carry out a Preliminary Hazard Identification (PHI) of the UKADGE system to identify SA-related hazards associated with other human, organisational and technical system elements that could fail to provide accurate or timely situational data to the WC. A HAZard and OPerability (HAZOP) style technique (see Figure 2.3) was used along with the UKADGE SA Interaction Model to identify the SA-related interaction hazards for UKADGE. The HAZOP was carried out based upon an assumption that the top-level UKADGE system hazard was, "Controller acts inappropriately due to lack of SA." The HAZOP guidewords used for this analysis were as follows:

HAZOP SA Data-flow Guidewords

NO (SA data): complete failure or late.

ERRONEOUS (SA data): non-detectable and incorrect.

The data collected from this HAZOP process is shown in Table 7.1. The PHI data in Table 7.1 shows that hazardous, high-level WC interactions were identified as those involving radio communications, situational data displays, the reporting team and the TACRO. This information was used to focus the SAPAT stage of Identifying Interaction Breakdowns on the hazardous SA-related interactions. The use of the comprehensive UKADGE SA Interaction Model shown in Figure 7.2 will be explored further in Chapter 8 when the associated modification to the ISSAM is explained in detail and a generic system interaction model is developed from the findings of this field study.

Hazard Ref.	SA Interaction Model Component	Functional Hazard Description
	Comms Sub-system	
C1		Provides NO comms
C2		Provides ERRONEOUS comms
	ICCS Display and DHS	
D1		Provides NO SA data
D2		Provides ERRONEOUS SA data
	Reporting Team	
R1		Provides NO requested control
R2		Provides ERRONEOUS requested control
R3		Provides NO feedback
R4		Provides ERRONEOUS feedback
	TACRO	
T1		Provides NO requested control
T2		Provides ERRONEOUS requested control
T3		Provides NO feedback
T4		Provides ERRONEOUS feedback

Table 7.1 - Preliminary Hazard List

SAPAT Stage 2 - Identify Interaction Breakdowns

During this stage of the data collection, the problematical actions and operations resulting from SA-related interaction breakdowns were identified during both the Scenario Development and Simulation phases of the USSS. Not all observed interaction breakdowns were hazardous in the context of system use, therefore the data collected during the PHI using the UKADGE SA Interaction Model was used to identify SA-related interaction breakdowns. The hazardous mediation breakdowns affecting the interaction between: WC←→ ICCS←→ Safe Control of Aircraft (this notation was introduced in section 4.3.2 and ←→ is used to depict the two-way mediating relationship) shown in Figure 7.1, were initially identified and categorised using the SA Process Model of SA and applying the principles of AT to direct the observation. A complete record of the observations made during this stage can be found in Appendix N.

Another important limitation of SAPAT was identified here as hazards associated with *both* interaction breakdowns and automatic interactions were identified during this data collection activity. Automatic interactions were discussed in Chapter 2 and can be characterised as interactions that normally require conscious actions but are achieved through automatic operation. In AT terms, these interactions are characterised as developmental changes from Operation → Action. A discussion is presented in Chapter 8 to explain how SAPAT was modified to address the implications of these findings.

In order to illustrate how the SA Process Model was used to analyse interaction breakdowns, a specific example is considered here. The USSS revealed that the system displayed many different alerts and alarms to the WC via the ITD. The UKADGE system requires individual alerts to be acknowledged or cancelled through a complicated keying sequence using the ITD, SFKs and the QWERTY keyboard (these ICCS interface components are described in detail in Chapter 5). However, the vast majority of alerts presented to the WCs are perceived to be irrelevant and distracting (this was confirmed during post-sortie interviews); also alerts are cancelled by the operator using a keying sequence which is consistent for all alert types regardless of priority. It was repeatedly observed that this alert-cancelling sequence of actions was carried out so frequently that what was intended by the system designer as a series of conscious actions had developed to become an automatic operation for the WC (see hazards P2 and S3 in Appendix N).

The hazards associated with this example can be considered. On all three occasions when two military aircraft were merged together as one indistinguishable plot on the Universal Console display, a SAGAT freeze point question revealed that the WCs could not state which aircraft was transmitting an emergency code denoting a communications failure. On these occasions the WCs were observed to have cancelled the ITD alerts containing this situational information as they carried out the now automatic switching sequence on a screen of multiple alerts – despite the fact that some safety-related alerts are highlighted in a different colour.

The SA Process Model was used here to analyse observable human-computer interactions and, specifically, to identify where the associated interaction breakdowns and automatic operations occurred in the sample-modify-direct cycle. In this particular example, the SA process failed in the sample-modify interaction as the alert-cancelling action following the situation sample was automated and thus the WC's awareness was only partially modified. It is vitally important to realise that the situational information described here was only safety-related in this specific context - on another occasion the alert information may have little relevance to safety. As well as the SA-related hazards involved with automated interactions, this example has also shown one way that the SAPAT and SAGAT data were integrated during the USSS data analysis.

7.2.2 Analysing Interaction Breakdowns

As expected, the application of the SAPAT approach to the analysis of the UKADGE system interactions provided qualitative data which was used to highlight specific SA acquisition and maintenance problems as shown in the example above. Also, as anticipated, the observational data derived from the USSS highlighted a number of hazards associated with interaction breakdowns while the subsequent post-sortie interview data provided an understanding of the WC's cognitive processes which were discussed in Chapter 2. It must be stressed here that the observations alone did not always reveal interaction breakdowns or automatic interactions, these were often revealed from the notes taken during the post-sortie interviews with the WC involved. [7] Any hazardous interaction revealed in this manner are shown in Appendix N.

In the alerts example given above, the sampled situation revealed to the operator that numerous alerts required acknowledgement and this level of information was used to modify the user awareness, however, the detailed information presented by each individual alert was not integrated into their state of awareness. The operator's situated action was to cancel multiple alerts as one, chunked, automatic operation. It was confirmed during post-sortie interviews that the users in these examples were conscious only of cancelling multiple alerts and their modified awareness therefore did not direct them to sample the situation for the cause of the alerts which provided safety-related information in some simulation contexts. The net result was that the WCs had incomplete subjective awareness of the situation despite the fact that the ICCS interface displayed the relevant information via the ITD.

[7] Notes taken during post-video interviews are available for analysis.

Analysing these interactions in terms of the SA model indicates that a breakdown occurs between sampling the situation and modifying the operator awareness.

7.3 PRODUCT-RELATED DATA

7.3.1 SAGAT Data Analysis

The SA product-related data was collected during the USSS through the application of the Situational Awareness Global Assessment Technique (SAGAT) variant described in Chapter 4. It was initially expected that SAGAT would produce only quantitative data, however, the simulations also produced qualitative observational and interview data as part of the SA Process Analysis Technique (SAPAT) described in the previous section. The different data types collected during the SAGAT simulations are examined in the remainder of this section.

Observational Data

The detailed interactions of the sample SAGAT simulation population were observed first hand and notes were taken when hazardous interaction breakdowns and automatic operations were observed. The observational data differed fundamentally from the other data collection methods as it was collected first-hand rather than retrospectively obtained from document reviews or interviews where hindsight-bias or memory decay could affect the interpretations. Another purpose of the USSS observational data was to verify that the ICCS system was used by the WCs in the formal, documented manner intended and to see if any informal changes to working practices had emerged through local adaptations or improvisations. A number of adaptations were noted, such as the use of personal checklists or target distance calculators, however none of the observed variations were related to interaction safety and therefore these are not considered further in this dissertation.

Informal and Semi-formal Interviews

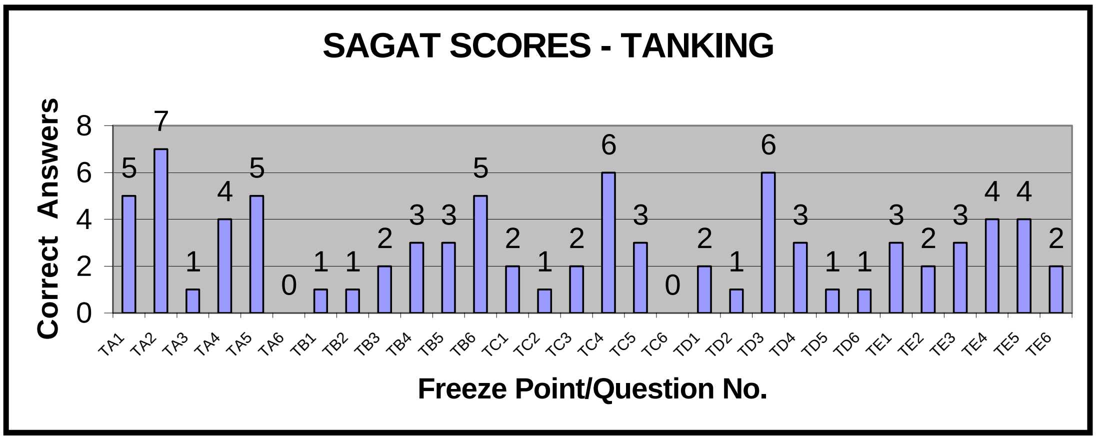
Semi-structured interviews were conducted in order to gather more specific information on the concepts that emerged from both the document reviews and the analysis of the questionnaire data which were undertaken during the Pilot Study. Semi-structured interviews were considered appropriate to the AT approach adopted for this research as they allowed the interviews to be generative, however, during the later stages of the research, the interviews became more structured to analyse the observed interaction breakdowns. 21 semi-formal interviews were conducted in total, each one lasting approximately 45 minutes and involving the sample SAGAT simulation population.

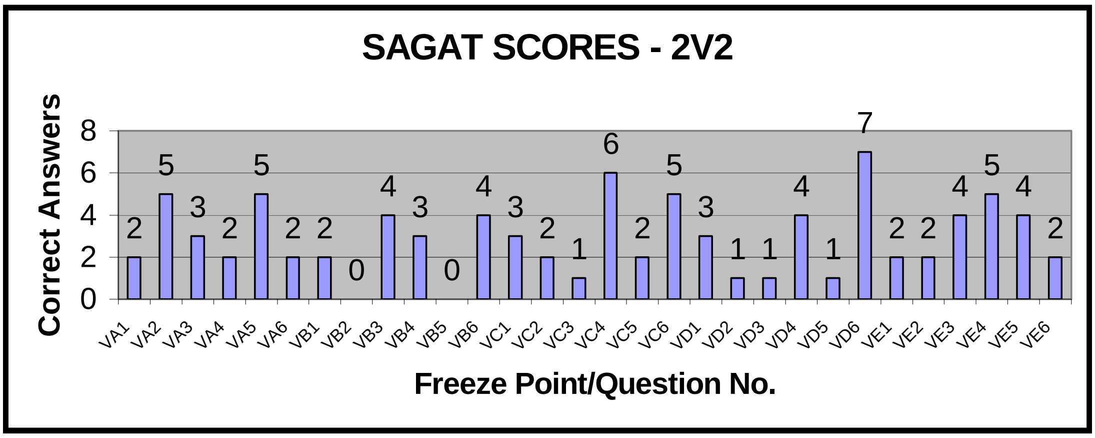
In practice it was found that detailed note-taking during interviews was very difficult as it was not conducive to maintaining a rapport with the interviewee. Nonetheless, sufficient data was collected to provide explanations for some of the observations. Specifically, the interviews were designed to focus on the observational data derived from the SAGAT simulations and also personal data concerning the individual WCs was collected to enable a weighting to be given to the analysis data.

SAGAT Data

The quantitative SAGAT data collected during the Simulation Exercise Phase of the USSS was input into a Microsoft Excel spreadsheet to enable analysis and graphical presentation of the SAGAT scores to be undertaken. The raw SAGAT scores for each sortie type are given in Appendices O, P and Q and a graphical summary of the field study SAGAT scores for each sortie type is provided in Figure 7.3 below.

The data was classified by Simulation Type, Freeze Point and Question Number. The simulations were identified by the letters T, V, and C to represent Tanking, 2v2 Split Frequency and Coffee 'C' respectively. Each freeze point was denoted by an individual letter in the range A - E and each question in the range 1 - 6. For example, the first question in the first freeze point of the tanking sortie was annotated as TA1. The specific use of the raw SAGAT data will be discussed in detail in Chapter 8.





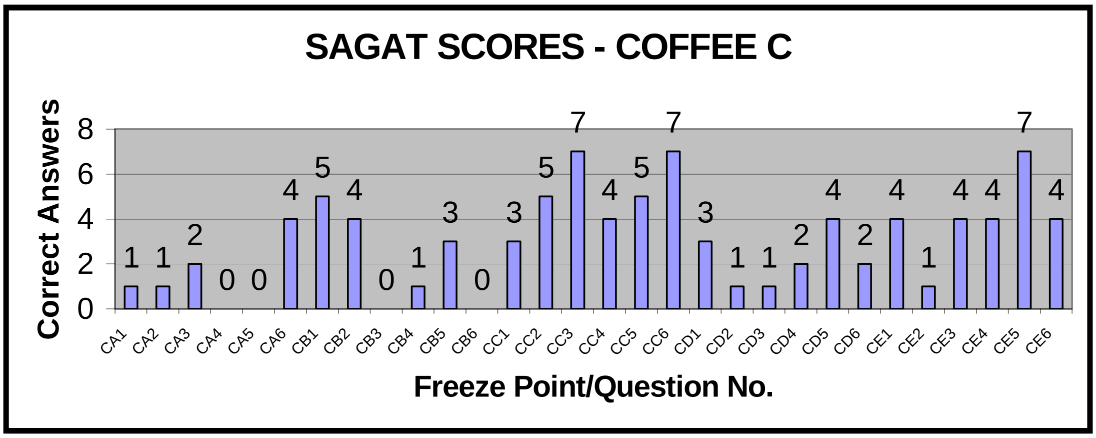


Figure 7.3 - Summary of Field Study SAGAT Data

7.3.2 SAGAT Data Interpretation

As expected, the application of SAGAT during the UKADGE field study provided quantitative data which could be used to infer the level of SA support provided by the ICCS interface. However, it should be understood that the raw SAGAT scores themselves do not give an absolute indication of SA and they can only provide a relative value of SA for the UKADGE system during a comparative safety assessment. This point will be discussed in more detail in Chapter 8 when discussing the applicability of ISSAM.

It was initially expected that the SAGAT data would be entirely quantitative; however when the data was analysed and it was noticed that a number of SAGAT questions were consistently answered incorrectly and an analysis of this provided additional qualitative data. For example, one question answered incorrectly in all simulations was the Tanking question TA6 (see Figure 7.3):

> *"How long before the stranger at UNI with mode 3A 5050, at its current speed and heading, reaches the boundary of AARA8?"*.

This question asks the WC, "How long is it before the potentially conflicting aircraft at the radio beacon designated UNI, with a fixed airframe identification number of 5050, at its current speed and heading, reaches the boundary of Air-to-Air Refuelling Area 8?" Following discussions with two experienced WCs, while viewing a re-run of the tanking simulation, it was concluded that this 'stranger' (potentially conflicting aircraft) was not a relevant safety factor. However, a number of other WC's, and significantly the domain expert that set the question initially, disagreed with this conclusion. On further investigation it became apparent that the situational elements considered relevant to safety are related to the experience level of the individual controller and the SAGAT questions are therefore clearly subjective.

Generally, a relatively inexperience WC would sample much more from the situational data and modify their awareness far more than a relatively experienced controller - regardless of the safety implications of the data. The data in Appendix R shows the overall SAGAT scores for each subject against the number of years of UKADGE experience for each subject. The data in Appendix R suggests that the relatively inexperienced WCs involved in the SAGAT simulations often scored higher than those with much more experience, which was contrary to the expectations held before the field-study commenced.

After consulting numerous WCs, it was concluded that the reason for this trend lies in the development of the SAGAT questions used in the simulations. As expected, the SAGAT question set was difficult to develop and the assistance of a qualified and competent WC was enlisted to develop objective questions that were sufficiently global to address the ‘sample’, ‘modify’ and ‘direct’ phases of the SA Process Model proposed in Chapter 4. However, it was discovered that the WC that set the questions had only 4 years experience in UKADGE and was therefore relatively inexperienced within the branch. The resulting SAGAT question set therefore addressed situational elements that were considered relevant to safety by the relatively inexperienced WC and the SAGAT simulations were therefore optimised for controllers with similar experience levels. It was concluded from this that:

- The experience of the questioner will be transferred to the questions and will affect the overall SAGAT scores of individual subjects.

- The safety-related elements of a situation are dependent upon the individual characteristics of the person interacting with the system. In short, what is safety-related to one person may not be to another.

This discussion partly explains why the quantitative USSS SAGAT data cannot be used to infer an absolute level of operator awareness as the SAGAT questions will inevitably be subjective. It is asserted here that the best that may be achieved is to derive a *relative* measure of coupling between a situation and the system operator. Another factor that affected the validity of the SAGAT data relates to a cultural issue concerning the Fighter Controllers generally.

As discussed in Chapter 5, the culture within the WC specialisation is generally very receptive to appraisal and honest self-assessment; it was therefore expected that the subjects would be candid when answering SAGAT simulations questions. A number of simulation practice runs were required to refine the simulations and the SAGAT questions relating to each freeze point. During the simulation runs it was discovered that the SAGAT questions had to be rephrased to avoid direct yes/no answers from the subjects. For example, an initial Tanking question TB1 (see Appendix K) asked the subjects:

> *“Did you notice the pair of strangers manoeuvring at Toppa?*

This question asks the WC, "Did you notice the pair of potentially conflicting aircraft manoeuvring at the radio beacon designated as Toppa?" During the practice runs the subjects *always* answered yes to this question and to almost all the other direct questions. However, it became clear with further questioning that they had not always noticed the conflicting aircraft. In order to avoid the direct question, this question was therefore rephrased as follows:

"What height are the pair of strangers manoeuvring at Toppa within +/ -5000ft?

When all the SAGAT questions were rephrased in this manner to ask an indirect question, the answer to the direct question could then be deduced from the subject's reply. It was concluded that, as in any other profession which requires a high degree of personal competence which is subject to periodic evaluation and re-certification, some UKADGE WCs were understandably reticent to admit to ignorance despite the assurances of anonymity given before the simulations began. From this discussion, it was deduced that, despite the initial expectations, some of the answers given by the UKADGE operators may not accurately reflect their actual state of SA and therefore the SAGAT data could not be used to provide an accurate absolute measure of operator awareness. However, the use of indirect questioning would increase the validity of the SAGAT scores. A discussion concerning the use of the quantitative SAGAT data is given in Chapter 8.

7.4 SUMMARY

This chapter has provided an explanation of the application of the ISSAM approach proposed in Chapter 4 which was used to collect, analyse and interpret the data from a field study of the UKADGE system. The chapter has introduced the SA process and product-related data that was collected during the field study and an explanation has been given concerning how this data was organised before offering an initial interpretation of the data. The activities presented in this chapter covered the requirements of the initial ISSAM Data Collection and Analysis phase shown in Table 4.2.

The chapter began with an examination of the SA process-related data collected through the application of SAPAT. The chapter then examined the SA product-related data collected during the SAGAT simulations which were conducted at various UKADGE sites. The chapter has also presented a discussion on the differences between the expectations of the field study outlined in Chapter 5 and the actual findings discussed in Chapter 6. An initial interpretation of the SAPAT and SAGAT data was also presented.

Attention was drawn to those specific areas of the field study where the interactive system safety analysis data collection techniques were found to be impractical. This chapter has explained how additional data was derived using modifications to the ISSAM and the chapter briefly introduced the modifications that were made to the original safety analysis method. A complete appraisal of ISSAM will be given in Chapter 8, including a detailed explanation for any modifications that were required to the original method resulting from the practical application of the method during the USSS.

Chapter 8

INTERACTIVE SAFETY ANALYSIS FOR COMPLEX SYSTEMS

8.1 INTRODUCTION

An Interactive System Safety Analysis Method (ISSAM) was proposed in Chapter 4, the intention being to develop the method through a field study of a complex, interactive system which was presented in Chapters 5 and explained in Chapter 6. The previous chapter presented the ISSAM data which was collected during a UKADGE System Safety Study (USSS) and an explanation of how this data was organised was given before offering an initial interpretation.

Having proposed and applied ISSAM, this chapter will present an appraisal of the method, including an explanation of how the method was modified during the USSS to overcome the theoretical shortcomings when applied in practice. In order to demonstrate the context-richness of ISSAM data compared with other observational analysis techniques, the chapter will present a discussion on the specific differences between the SA process data and typical task analysis data with an example taken from the observations made during the USSS.

The chapter will examine the practical application of the ISSAM safety analysis method with reference to the different system life-cycle safety activities introduced previously in Chapter 2. The chapter will present a specific example of how interactive system safety assurance can be provided through a safety-case argument that relies on the evidence gathered through the application of the SA Process Analysis Technique (SAPAT). The chapter will also present an argument for the use of ISSAM, and specifically the proposed SA Global Assessment Technique (SAGAT) variant, as a relative measure of interactive system safety.

The chapter will conclude with a brief discussion of the interaction design implications of the USSS findings. In the light of these discussions, the chapter will then present a validated and modified version of ISSAM together with a discussion of the limitations of the application of this safety analysis method which will conclude this chapter.

8.2 VALIDATING ISSAM

The ISSAM method is intended to be coherent with the Situated Cognition perspective of SA which was proposed in Chapter 3. From a Situated Cognition perspective, both the process of acquiring and maintaining SA in context and the actual awareness product assimilated by the system operator assume equal importance. ISSAM was proposed to provide a method for generating, analysing and interpreting SA-related data and it was shown in Chapter 4 how this method is founded on the fundamental principles of AT.

A field study was undertaken to apply ISSAM to the study of a complex, interactive system and the data generated from this study was examined in the previous chapter. In order to develop and validate ISSAM, it is necessary to show that the data generated during the field study was consistent with AT principles and to show how the resultant SA process and product-related data and interpretations are context-rich.

8.2.1 ISSAM Process-Related Data

In order to demonstrate the richness of the SA *process* data that was generated through the application of ISSAM, an example is presented here of the typical WC interactions motivated by the process of updating SA. The following data fragment (extracted from Roke 1997) shows some task analysis data which originates from observing a WC during what was classified by the observer as an SA monitoring task (denoted as T):

Task(T) or Action(A)	Task/Action	Start Time	End Time
T	Monitoring/Situational Awareness	00:19:00.8	00:19:06.1
A	Look at Radar Display	00:19:00.8	00:19:06.1
A	Use Keyboard	00:19:04.46	00:19:05.03
A	Use Rollerball	00:19:01.5	00:19:03.7

Table 8.1 - Task Analysis Data Fragment 1

This task analysis data fragment, taken between 00:19:00.8 and 00:19:06.1, describes the sequence of individual actions (denoted as A) that were carried out by the WC and it also indicates their relative timing. The task analysis data does not, however, offer any explanation for the motivation behind the WC's actions and also the context of the task is not included in the data at all. The data simply describes *what* was done by the WC but it does not give any explanation as to *why* it was done therefore it cannot reveal any causal relationships that underlie the activity of maintaining SA.

Lewin's classical study (1935) showed the severe limitations associated with purely phenomenological analysis based on external features (phenotypes) with what he calls genotypic analysis where a phenomenon is explained on the basis of its origin rather than its outward appearance. The task analysis data shown here presents only the phenotypes associated with the maintenance of SA. The importance of this is can be recognised by considering another task analysis data fragment (also extracted from Roke 1997):

Task(T) or Action(A)	Task/Action	Start Time	End Time
T	Monitoring/Situational Awareness	00:21:02.92	00:21:21.05
A	Look at Radar Display	00:21:09.1	00:21:21.05
A	Use Keyboard	00:21:19.96	00:21:21.03
A	Use Rollerball	00:21:10.7	00:21:12.5
A	Use Rollerball	00:21:13.69	00:21:14.9
A	Use Rollerball	00:21:02.92	00:21:05.62
A	Use Rollerball	00:21:07.39	00:21:08.55

Table 8.2 - Task Analysis Data Fragment 2

In this task analysis fragment, taken this time between 00:21:02.92 and 00:21:21.05, it can be seen that the same actions are carried out as in the first fragment. However, the data here does not explain how or why this SA monitoring activity may differ from the previous one as the interaction context is missing. For example, it is not known what information the WC samples from the situation while looking at the radar display, and whether the information is safety-related in this context. Also, task analysis methods that generate data such as that shown in Tables 8.1 and 8.2 often present data on *every* observed system interaction which can result in an overwhelming quantity of data for subsequent analysis and interpretation.

With ISSAM, safety is the focus and therefore the method does not attempt to analyse every system interaction, it aims to identify and explain only the *hazardous* system interactions in the context of system use. To show how the ISSAM data differs from the task analysis data shown above, we can consider the data derived from the observation and subsequent analysis of a similar SA maintenance task and apply SAPAT to focus on an interaction breakdown (from Appendix N):

ISSAM Phase (Hazard No.)	Interaction Hazard Type	SA Process Breakdown	Interaction Description	SA Source/ICCS Interface Components	Associated Hazard(s)
Video Analysis (V1)	Breakdown (Operation → Action)	Sample situation	Obtaining SA data from ITD - Emergency squawk	Situational Data/SFK, ITD, Qwerty Keyboard	No SA Data

Table 8.3 - SAPAT Data Fragment

The major difference between SAPAT and typical task analysis methods can be seen from a comparison of the data in Table 8.3 with the previous task analysis data shown in Tables 8.1 and 8.2. The SAPAT data concerns itself only with hazardous interactions and the data provides some explanation for the motivation for the WC's actions, as some of the context of the task is included in this data. The context-rich ISSAM data in this example contains contextual information regarding the phase of the SA acquisition process, what the WC was attempting to achieve, what data was being sampled, what components of the UKADGE system were being used, and finally the hazard associated with the interaction breakdown.

It should be pointed out that this argument for phenomenological explanation is not intended to imply that process description is neither necessary or useful. To clarify the position taken in this dissertation, objective explanation would be impossible without accurate description and therefore it is asserted here that a comprehensive, scientific analysis method must include both.

The practical application of SAPAT to the USSS did reveal that an important modification was required to the initial analysis method. The SAPAT data distinguishes between the status of a particular process (action or operation) using the AT hierarchy of activity principle as described in Table 4.1. An understanding of the level of a process within this hierarchy can also help the researcher to anticipate the direction of developmental changes. Significantly, it was observed during the USSS that developmental changes relating to automatic operations and their associated problems may be changes that relate to the technical conditions for interaction.

The implications of this are important. From this, it has been shown that automated interactions can circumvent the Sample-Modify-Direct SA process cycle in some contexts and the operator may not assimilate safety-related situational information. If safety is an issue, hazardous interactions can be identified and analysed using the ISSAM analysis method outlined in this dissertation and design solutions can be proposed that anticipate developmental changes which may occur with system use. It would then be possible for designers to use interaction designs that force the situational sampling in order to avoid the automation of actions to prevent them from developing into unconscious operations for the operator.

8.2.2 ISSAM Product-Related Data

Although it was initially expected that SAGAT would produce only quantitative data, the simulations also produced qualitative observational and interview data which was used by the SAPAT analysis and this data was described in section 7.3. Superficially, it may seem difficult to argue that the numerical SAGAT data is consistent with the principles of AT and the Situated Cognition perspective of SA. However it is argued here that the context of the UKADGE system was encapsulated within the high-fidelity simulations and the SAGAT questions which were deliberately developed by experts to capture the system context.

The detailed explanation of the field study activities given in Chapter 6 shows that both the Pilot Study and the main USSS focused on the study of the UKADGE system in context. For example, the SAGAT simulations were all conducted within live operations rooms and the WCs were interacting with the system in exactly the same manner as in live operations to reproduce the context of operations faithfully (notwithstanding the disadvantages of the obvious obtrusiveness of the SAGAT freeze points which were discussed in Chapter 3). The resulting data generated from the application of the SAGAT variant which was used in this study contains context-rich information relating to the cognition of the UKADGE operators *in situ*, which is entirely consistent with AT and a Situated Cognition approach adopted by the ISSAM. An explanation of the specific use of the quantitative SAGAT data will be provided in section 8.3.2.

As mentioned previously, the qualitative data derived from the SAGAT simulations also contained contextual information relating to the SA process. In order to illustrate how the SAGAT simulations were used to provide context-rich data, which was consistent with the SA Process Model and covered all phases of the Sample-Modify-Direct cycle, a specific example is considered here. One question that was designed to obtain safety-related information concerning the subject's SA in the context of simulated operations was the following 2V2 question number VA4 (see Appendix K):

> "*What is the mode 3C of Scorcher 3?*"

This question asks the WC, "What is the current height of the aircraft with the call-sign Scorcher 3?" It is necessary for the WC to consciously direct their actions to interact with the ICCS interface in order to sample the situational data to obtain safety-related information concerning the height of a particular aircraft plot displayed on the ICCS UC. This safety-related data is known as Mode 3C height information which is not associated automatically with each radar plot on the UC display. This SA maintenance process is achieved through an ICCS interaction sequence using the Rolling Ball cursor and three keying actions on the

Special Function Keys (SFKs). This sequence is known as a Plot System Identification Function (or Plot SIF).

Observational data taken during the simulations revealed that *all* the WCs had carried out a Plot SIF sequence on the Scorcher 3 aircraft to obtain the height shortly before the SAGAT question was asked. However, an analysis of the SAGAT simulation data in Figure 7.3 revealed that only two WCs from seven questioned knew the correct answer to this question despite the unquestionable safety-related nature of the information relating to the height of an aircraft under the direct control of the WC.

During the post-simulation analysis (see Appendix M), the two subjects that had modified their awareness following the Plot SIF revealed how their subsequent system interactions were directed as result (see Appendix N for hazardous interaction log).[8] Also, and perhaps more important to this dissertation, of the five WCs interviewed that had incorrectly answered this SAGAT question, four subjects stated that although they had carried out the Plot SIF function, they had not been consciously aware of the quantitative result of this interaction sequence. In other words, they had carried out the actions automatically but had not consciously assimilated the aircraft height information. A more detailed examination revealed that the Plot SIF interaction sequence had become so familiar that it had developed into an automatic operation for all the subjects that answered this SAGAT question. The WCs had repeatedly been observed playing the SFKs in rapid succession almost like playing a musical instrument.

Figure 8.1 summarises how, in this example, different data collection methods were used during the application of SAGAT to derive context-rich data consistent with the SA Process Model and the theoretical principles of AT presented in Chapter 4:

Sample	- Observation during SAGAT simulation
Modify	- SAGAT Data
Direct	- Post-SAGAT analysis questions

Figure 8.1 – ISSAM Data Collection Methods

[8] Notes taken during post-simulation interviews are available for analysis.

It can be seen from this example that the SAGAT simulation technique provided data consistent with the SA Process Model which in turn was derived from the Situated Cognition perspective of SA that was shown to be consistent with the principles of AT in Chapter 4. From a Situated Cognition perspective of SA, this integrated SA data provided vital system safety information and revealed *what must be known* by a UKADGE WC to enable him/her to update his/her awareness when interacting within the dynamic Air Defence environment.

Having presented the arguments for the validity of the ISSAM for the safety analysis of complex, interactive systems, it is necessary to discuss the practical application of such a method. The following section will deal with this question.

8.3 THE PRACTICAL APPLICATION OF ISSAM

The previous sections have argued for the validity of the data generated from the application of ISSAM to the analysis of interaction safety in complex, interactive systems such as the UKADGE system. However, a method such as ISSAM can only add value to the system life-cycle if it can be applied practically to generate data that is useful to the system developer. In Chapter 2, a system life-cycle model was introduced based upon the STARTS 'V' Life-cycle Model (STARTS 1989).

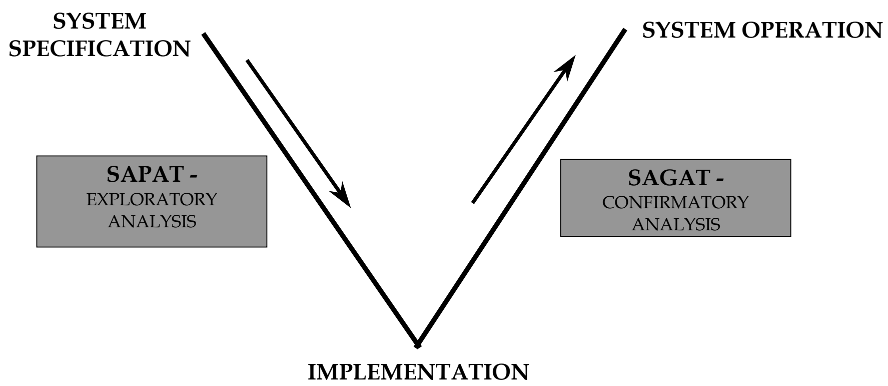


Figure 8.2 – ISSAM Life-Cycle Phases (adapted from STARTS 1989)

In Figure 8.2 the ‘V’ Model is adapted to show when ISSAM can be applied during the system life-cycle. The remainder of this section will show how ISSAM can be applied and the uses of the data collection, analysis and interpretations.

8.3.1 Exploratory Safety Analysis

As discussed in Chapter 2, exploratory analysis techniques should ideally enable system developers to identify interaction hazards as early in the life-cycle as possible to reduce the potential cost of system redesign and rework. However, this ideal must be balanced against the philosophy espoused in this dissertation to analyse system interactions *in context*. This requirement implies that a fully functional system must be available to analyse and an advanced prototype may be the minimum practical requirement. As shown in Figure 8.2, SAPAT was used during the USSS for an exploratory analysis of interaction safety and it was used specifically for the identification and analysis of hazardous interactions and also for the derivation of system safety requirements.

It has been shown in this dissertation that SAPAT can be used as a framework for the identification and analysis of situated hazards relating to operator awareness in the context of system use. Specifically, there are two ways in which the SAPAT technique 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 which were discussed in Chapter 2. 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 will be discussed in the following sections.

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 Preliminary Hazard Identification (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 on the UKADGE EDDIE asks the operator the final question:

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

The EDDIE (see Chapter 5 for more details) uses a Windows, Icons Menus and Pull Down style of interface and this particular interaction is 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. It was observed during a live Air Defence sortie, that the WCA was rapidly interacting with the system and rearranging the display when the Exit Menu was invoked and the Yes button was inadvertently selected closing all the windows displaying SA-related information (see hazard S9 in Appendix N). This erroneous operation caused a delay of approximately 2 minutes before the screen set-up could be restored to display the situational information.

An analysis of this interaction revealed, through discussion with the WCA, that the action of selecting a button from the Exit Menu on a normal system shutdown had develop into an automatic operation without the operator being consciously aware of the interaction - until the display was reset erroneously. In this example, we have identified what can be regarded as an *unplanned* automatic operation which is carried out without the conscious formulation of a plan. Reason (1990) asserted that the term *human* error can only be meaningfully applied to planned actions that fail to achieve their desired consequences without some unforeseeable intervention. It has been shown 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 was seen in the Plot SIF example given in section 8.2.2. 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.

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 for practitioners and researchers to analyse and categorise SA-related problems. For example, the SA Process Model was used to question where the problems in particular situations might have arisen: what information did the WCs 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 WC'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 were identified during the USSS. As WCs integrated sampled information, for example, the erroneous modification of their awareness may have loosened the degree of dynamic coupling between their awareness and the actual situation, leading to a reduction in SA.

These exploratory SAPAT analyses, concerning interaction breakdowns and automated interactions, deal with the design trade-off between usability and safety. SAPAT can be used to identify those areas of an interactive system where safety should take precedence. 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 identified hazardous interactions, safety is more important and this leads to this study suggesting the following 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 interaction should force the interaction to remain a conscious action.*

As a direct result of the USSS findings, the safety requirements for a replacement UKADGE interface now specify that the replacement system must balance the requirements of both SA and usability in the design of interfaces and interactions (UCMP 1998).

8.3.2 Confirmatory Safety Analysis

As discussed in Chapter 2, confirmatory analyses can be used later in the system life-cycle both to generate numerical data and to highlight hazardous areas of an interactive system design that may require additional risk reduction through redesign. Figure 8.2 shows that SAGAT was used during the USSS for the confirmatory analysis of system safety by providing a comparative measure of SA support.

As discussed in Chapter 2, current interactive system evaluation methods concentrate almost entirely on usability issues. Clearly, the usability of an interface will affect the frequency and types of operator errors that can be made; however, usability and safety can sometimes be mutually exclusive system properties as shown in this dissertation. For example, it has been shown that enhancing the usability of an interface by reducing the number of keying actions to perform a given task may affect the safety of an interface by increasing the probability of a hazardous action. Any design trade-off between usability and safety may also affect the reliability of the cognitive processes involved with acquiring and maintaining SA. Clearly, to have practical application, interactive safety must be specified in quantifiable or measurable terms in a similar manner to usability.

This dissertation has argued that SA is a critical attribute for evaluating the safety of complex, interactive systems situated in dynamic environments. It was suggested in Chapter 3 that SA is a dynamic concept that exists at the interface between an operator and the environment. A pragmatic definition of SA was given as the fit between a subjective interpretation (awareness) of a situation and an objective measure of the situation built through an individual's interaction with their environment. Based on this perspective, it was also suggested that SA can provide interactive systems designers with a quantitative measure of the dynamic coupling between an operator and a particular situation.

From this discussion, it is a contention of this dissertation that SA is a critical safety attribute that can be used in the context of interactive systems to undertake confirmatory analyses of the relative safety of human-computer interactions in context. This dissertation has presented aspects of a field-study of the UKADGE system and proposed ISSAM as a method of evaluating both the process and the product of SA.

It is asserted here that the quantitative SAGAT data generated from the application of ISSAM can be used to produce benchmark data relating to the safety of a system interface. The data collected during the USSS can then be used to give a *relative* measure of the safety of a replacement interactive system compared with the UKADGE system.

A system developer can assess the safety of a replacement UKADGE system using the ISSAM SAGAT method and data described in this dissertation. This will require the system developer to carry out an assessment of a replacement interface using exactly the same Simulation Development outputs (simulations, scripts, SAGAT questions) and Simulation Exercise conditions described in section 6.3.2. of this dissertation.

Also, to use the SAGAT data for a comparison of system safety, it would be essential to ensure that a similar sample user population is used as shown in Table 6.1 to remove any bias introduced through individual WC characteristics. This SAGAT-based comparative assessment technique is summarised in Figure 8.3.

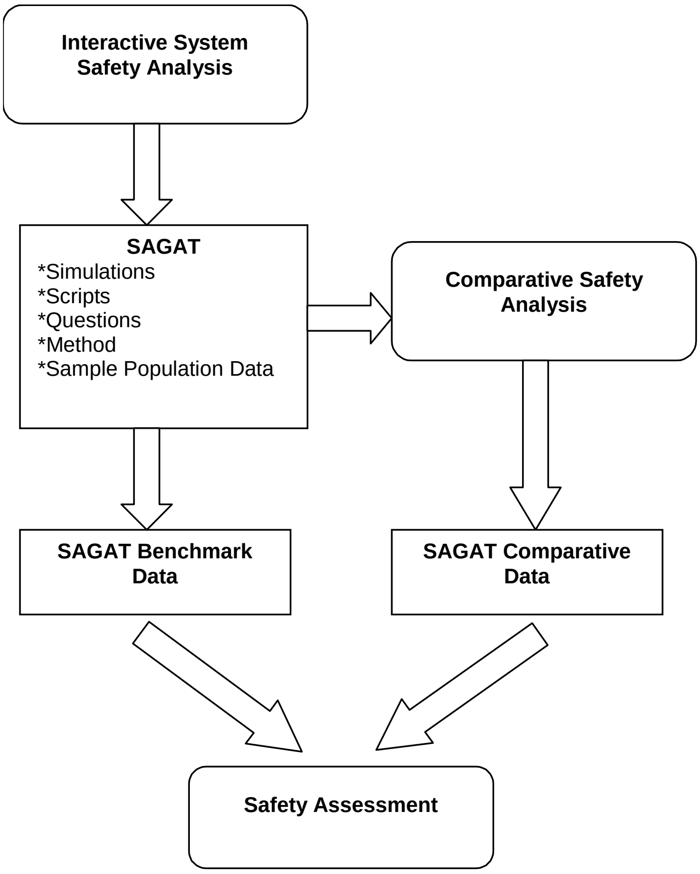


Figure 8.3 - Comparative Safety Assessment Technique

The application of ISSAM during the USSS provided quantitative, benchmark safety data which can be used for comparison with other ICCS interface design solutions. This will provide a system developer with a method of assessing the safety of any interactive system relative to another. The initial findings of the USSS have already directed the UKADGE system developers to specify SA as a critical safety attribute for a replacement ICCS interface (UCMP 1998).

8.3.3 ISSAM Data as Safety Case Evidence

As this dissertation has already suggested, usability and safety can be mutually exclusive properties and it has been shown how ISSAM can be used to identify when safety should be afforded the priority. Making use of usability evidence, such as the speed of interaction, to support claims that aspects of the system are safe may be misleading. Instead, since safety-related systems are primarily concerned with hazardous failures, safety arguments should focus on these failures and the evidence directly related to them. As discussed previously, the quantitative data derived from SAPAT analyses can be used to frame safety claims relating to interactive systems. The safety claim relationship depicted in Figure 2.5 can be helpful here, in supporting the substantiation of a safety claim as highlighted in the following example:

Hazardous Failure:	Controller acts inappropriately due to lack of SA.
Claim:	Interface design enables adequate level of SA to be acquired and maintained.
Argument:	All safety-significant interactions modify operator awareness.
Evidence A:	No automatic hazardous interactions observed during simulations.
Evidence B:	Hazardous interactions conform to dynamic SA model with no discontinuities, e.g., the sample/modify/direct cycle is followed throughout the user's interaction with the system.

This safety claim would use the SAPAT data as direct evidence to support the assertions made here.

A system safety case also relies on empirical evidence to show that a required level of safety assurance has been achieved and that it is maintained throughout the system lifetime. SAGAT data can be used for this purpose as an interactive system may be benchmarked to derive SAGAT data. A comparative safety assessment can then be undertaken at a later date to provide empirical evidence to support required safety claims.

8.4 A GENERAL INTERACTIVE SYSTEM SAFETY ANALYSIS METHOD

8.4.1 Developing ISSAM for General Application

Chapter 7 explained how additional field study data was derived using modifications to ISSAM and the chapter briefly introduced the modifications which were made. An explanation is therefore required for the modifications that were made as a result of the impracticalities of the method discovered during the USSS. Briefly, the USSS revealed a requirement for specific modifications which included the development of an SA Interaction Model, an addition to SAPAT and an elaboration of ISSAM. These changes will be explained in this section before presenting a summary of a general ISSAM which can be used for the development of complex, interactive systems similar to the UKADGE system.

A Generic SA Interaction Model

A UKADGE SA Interaction Model was developed in Chapter 7 and presented in Figure 7.2 to show the complete human and technical UKADGE system functionality in terms of SA. It was shown that the UKADGE SA Interaction Model was required to enable a Preliminary Hazard Identification (PHI) to be undertaken to consider SA-related interactions from the WC's perspective and to identify those which are hazardous as part of the ISSAM SA Process Analysis.

For ISSAM to have general applicability, it is therefore necessary to develop a generic SA Interaction Model that uses the SA Process Model to represent the human factor from an operator's perspective and depicting the possible interactions with the sources of situational data. A generic model is presented in Figure 8.4.[2]

[2] The author acknowledges the intellectual input of Squadron Leader James Savage in developing this Generic SA Interaction Model.

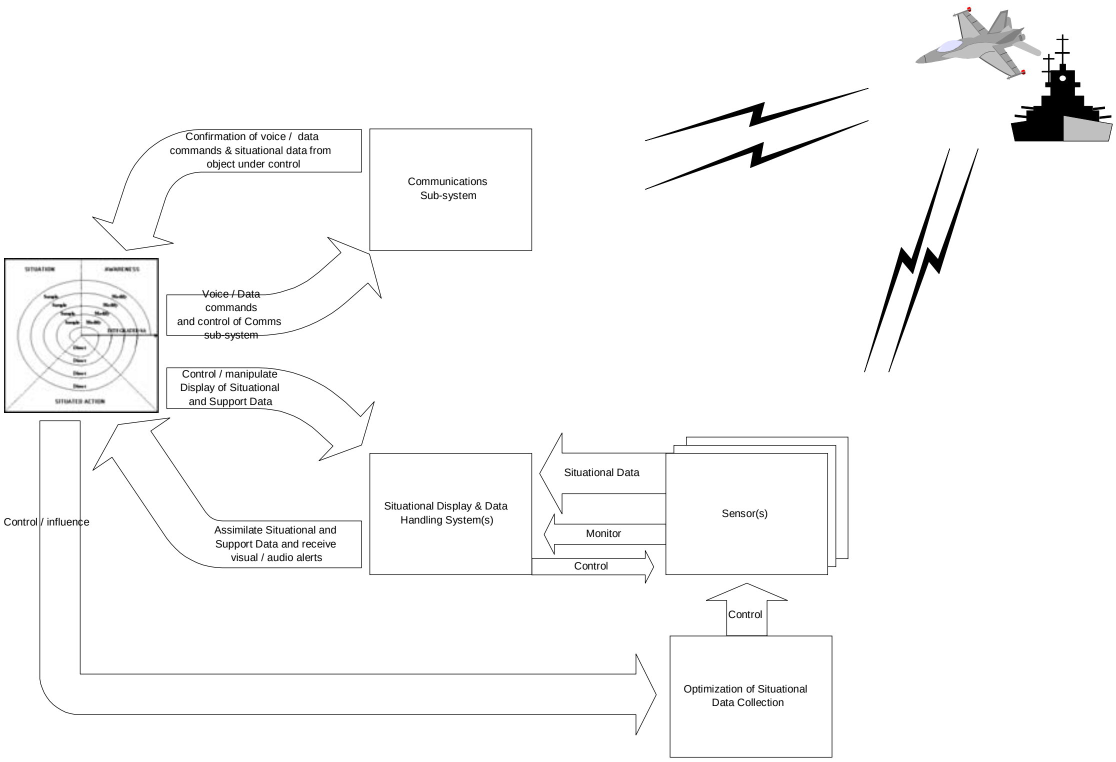


Figure 8.4 - A Generic SA Interaction Model

It can be seen that the generic SA Interaction Model in Figure 8.4 was derived from the UKADGE model. The model represents the functionality of interactive systems similar to the UKADGE system. These systems generally present situational data to an operator through a communications sub-system, a display and (possibly) a remote method of optimising the situational data collection sensors involving other system operators. For example, a railway control room operator will sample situational 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.

This generic SA Interaction Model can be said to represent both the Subject ←→Tool←→Object and the Subject←→Community←→Object mediating relationships of an activity (see Figure 4.1). The model encapsulates the SA-related interactions concerning both the Operator←→Interface←→Control Task and the Operator←→Other Operators←→Control Task. In summary, the generic SA Interaction Model enables a PHI can be carried out on complex, interactive systems as part of SAPAT.

An Addition to SAPAT

With the identification of a requirement for a PHI during the SA process analysis, it is necessary to modify the initial SAPAT proposed in Figure 4.3 of Chapter 4. The modified version of SAPAT is presented in Figure 8.5.

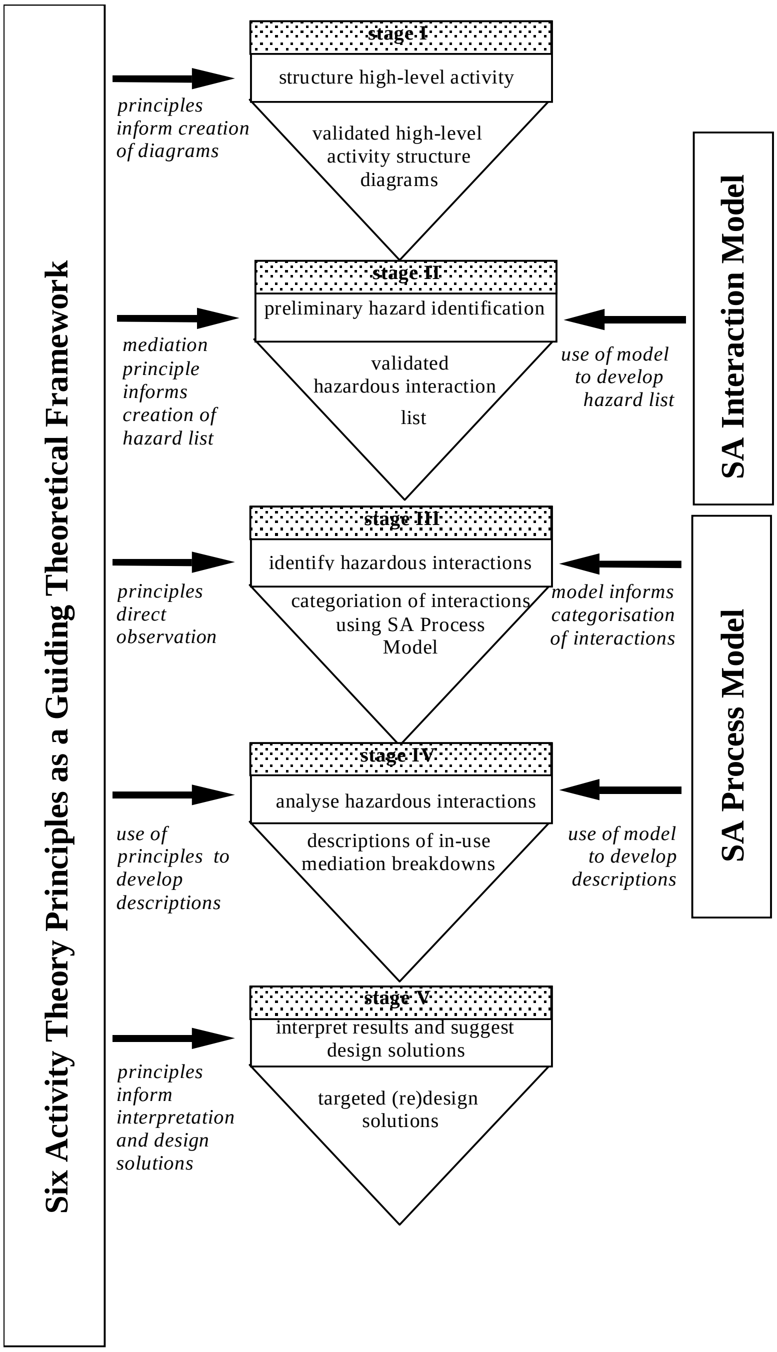


Figure 8.5 - SA Process Analysis Technique (SAPAT)

The amended SAPAT diagram now shows five analysis stages including the additional PHI stage which uses a system SA Interaction Model as input to develop a preliminary hazard list of system interaction hazards such as that shown in Table 7.1 for the UKADGE system. This hazard identification information can then be used to focus the following SAPAT stage on the hazardous SA-related interaction breakdowns. This PHI stage is informed by the principles of AT and it can be said that the techniques applied during this stage focuses on the identification of hazardous mediations within an interactive system.

A Modified ISSAM

Having previously developed the SA Interaction Model and integrated its use into the amended SAPAT, it is also necessary to modify the initial ISSAM proposed in Table 4.2 of Chapter 4.

A summary of the validated ISSAM is given in Figure 8.6 which shows the relationships between the theoretical principles, models and techniques that contribute to the method. Figure 8.6 also shows the practical uses of the data derived from an application of ISSAM.

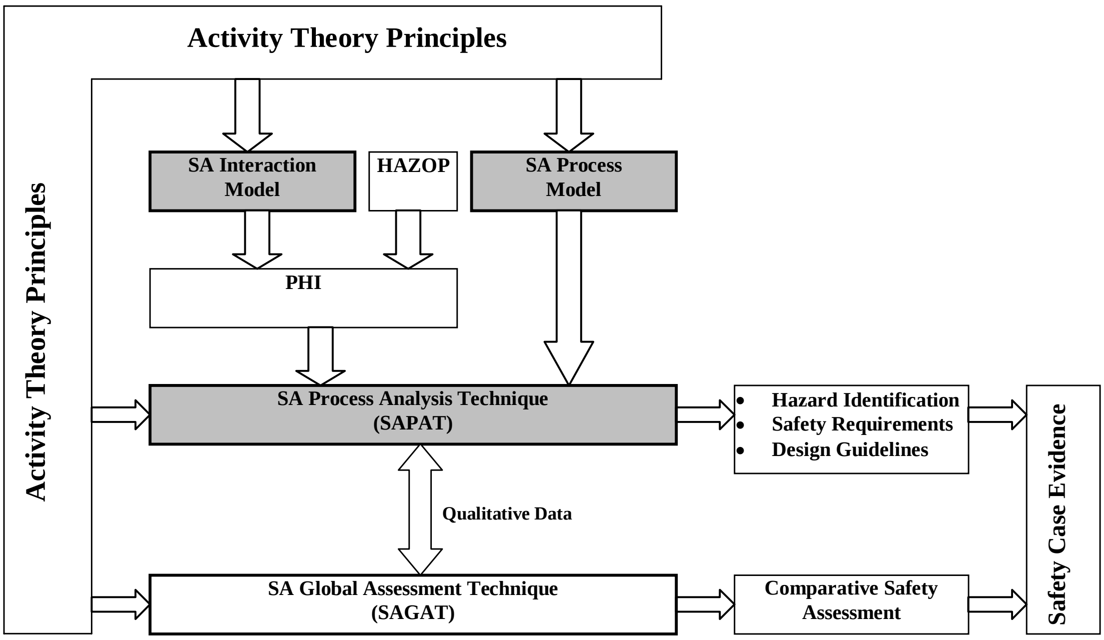


Figure 8.6 - ISSAM Summary

ISSAM Phase	SAGAT Activity	Output from ISSAM Techniques	SAPAT Stage
1. System Familiarisation	**Pilot Study** • Observation • Interviews • Questionnaire	• Qualitative Data • ID Simulation Scenarios	**1.** Structure High Level Activity
2. Preliminary Hazard Identification (PHI)	**Scenario Development** • Video/Data Recording • Post-Video Interview	• Preliminary Hazard List • Qualitative Data	**2.** Preliminary Hazard Identification **3.** Identify Hazardous Interactions
3. Safety & Hazard Analysis (SHA)	**Simulation** • Simulation Production • Simulation Exercise • Simulation Interview	• Quantitative SAGAT Data • Qualitative Data	**3.** Identify Hazardous Interactions **4**. Analyse Hazardous Interactions
4. Safety Assessment		• Benchmark Safety Data • Hazard Identification • Safety Requirements • Design Guidelines	**5.** Interpret Results

Table 8.4 - Interactive System Safety Analysis Method (ISSAM)

The modified version of ISSAM is presented in Table 8.4. The modified ISSAM in Table 8.4 now proposes four phases of the method where SAGAT and SAPAT activities are undertaken in parallel. Table 8.4 shows that the data derived from the different SA analysis techniques can be used by each other. For example, in the System Familiarisation Phase of ISSAM, the qualitative data derived from the SAGAT activities is used during the SAPAT Structure High-Level Activity stage.

8.4.2 The Limitations of ISSAM

It has been shown how ISSAM can provide a comprehensive method for analysing interactive system safety and for generating safety case evidence that may be used to provide system safety assurance. The previous sections have given an appraisal of ISSAM and have explored the specific application of the method. This section will now examine the limitations of ISSAM to provide a balanced view of the practicalities involved with the method's application.

In Chapter 2 it was argued that there is no such thing as absolute system safety and that safety and risk are inextricably linked. It was therefore concluded that the task of producing a safety-related system can be seen as a process of risk management with risk being defined as the product of the severity and the probability of an identified hazard. From this, it was shown that safety-related 'system' designers undertake safety analyses which integrate the concept of hazards with that of risk.

A possible limitation with the proposed ISSAM is that the method does not deal directly with the concept of risk assessment. Although ISSAM does propose the identification and analysis of interaction hazards, it does not attempt to quantify either the severity or the probability of occurrence of the identified interaction hazards.

However, it was also argued in Chapter 2 that interactive systems present unique hazards and problems when developing safety-related systems. It is more difficult to predict the possible mental states of an operator in a complex system than the possible physical states of the system being controlled. Even if it were possible to identify all the possible mental states and their effects on human behaviour, the difficulty of estimating the probability of occurrence of each state remains. Human Reliability Analysis (HRA) methods and techniques have attempted to address this issue, however, much of this research has been dominated by assumptions that apply to technical systems and often these do not translate to human systems (Woods *et al.* 1994).

It is argued here that human error probability is best examined from a cognitive perspective as traditional reliability engineering techniques do not fit well with human factors issues. While it is asserted that ISSAM can be used to carry out safety analyses, it is not claimed here that ISSAM can provide system developers with a method for the quantification of the risks associated with human-computer interactions or with human-human interactions. Nevertheless, ISSAM can assist with the identification, reduction and mitigation of risk in interactive systems.

We can also see from Figure 8.6 that ISSAM is a complicated integration of theoretical principles, derived models and techniques which together constitute a comprehensive safety analysis method. From the description of the Pilot Study and the USSS given in Chapters 5 and 6 it can also be understood that the resources required to apply ISSAM to the analysis of system safety can be considerable. From this, it could be concluded that ISSAM is too costly to use. However, this argument is simplistic and fails to recognise the financial and human cost of neglecting safety in high risk systems where the cost of a single accident would typically outweigh the cost of applying ISSAM.

In Chapter 2 it was shown that risk can be considered tolerable if it has been reduced to the lowest practicable level commensurate with the cost of further reduction. This is known as the ALARP (As Low As Reasonably Practicable) principle which is shown in Figure 2.1. Clearly, it would not be reasonable to apply ISSAM to the analysis of any system where the associated benefits in terms of risk reduction would not be worthwhile. It is recognised that the ISSAM approach is not a practical method to apply to simple systems where the risks are relatively small.

For the successful application of ISSAM, a system must have the functionality available for high-fidelity simulations to be developed and exercised. The fundamental theoretical approach advocated by AT, and by association ISSAM, is that the identification of hazardous interactions can only be meaningfully achieved in context. This presents a limitation as the system must be installed with an advanced level of functionality for the simulations to be realistic and the ISSAM data to be meaningful.

It is however claimed in this dissertation that ISSAM would be reasonably practical to apply to the analysis of complex, interactive systems where the associated risks are considered to justify the cost. Typical complex, interactive systems with an associated high risk would be civil Air Traffic Control systems, Nuclear Power plants or Chemical Process Control systems, for example.

8.5 SUMMARY

This chapter has presented an appraisal of the Interactive System Safety Analysis Method (ISSAM), including an explanation of how the method was modified during the USSS to overcome the theoretical shortcomings when applied in practice. In order to demonstrate the context-richness of ISSAM data, the chapter also presented a discussion on the specific differences between the SA process data and typical task analysis data with an example taken from the observations made during the USSS.

The chapter discussed the practical application of the ISSAM safety analysis method with reference to the ‘V’ Model system life-cycle safety activities. Specifically, the chapter explained how ISSAM can be used to support both the exploratory and confirmatory analyses of the ‘V’ Model. The chapter presented a specific example of how interactive system safety assurance can be provided through a safety-case argument that relies on the evidence gathered through the application of SAPAT. The chapter also presented a method for using the quantitative SAGAT data for the comparative safety analysis of interactive systems.

The chapter concluded with a brief discussion of the interaction design implications of the USSS findings. In the light of these discussions, the chapter finally presented a validated and modified version of ISSAM together with a discussion on the limitations of the application of this safety analysis method.

Chapter 9

CONCLUSIONS AND FUTURE RESEARCH ISSUES

9.1 INTRODUCTION

This dissertation began with a discussion concerning the problems associated with the development of complex, interactive systems which are integrated into complicated social and organisational settings. To make matters more difficult, it was shown that complex systems often rely on the complex physical and cognitive capabilities of the operators for their safe operation. Complex systems such as these were characterised as systems that support dynamic processes involving large number of hardware, software and human elements that interact in many different ways.

Complex, interactive systems are increasingly being integrated into social contexts where their correct design and operation is essential in order to ensure the safety of the general public and the environment. This dissertation has focused on the situated analysis of complex, interactive systems which are operated in a safety-related context. The broad aim of this dissertation was to undertake an analysis of situational awareness and to evaluate its relationship to complex, interactive system safety and this chapter will consider how this aim has been achieved.

The chapter will begin by briefly reviewing the aims and achievements of each chapter within this dissertation in order to set the context for the remainder of the discussion. This chapter will summarise the findings of the research undertaken for this dissertation in the context of both safety and SA.

ISSAM was developed as a general method for analysing the safety of complex, interactive systems and this chapter will expand on the discussion presented in Chapter 8 to show how ISSAM can be useful to systems development practitioners. This discussion will elaborate on the academic and practical contribution of this research to the field. The chapter will then integrate the theoretical conclusions of the literature review with the interpretations from the field study in order to demonstrate that the aim and objectives of this research have been fulfilled. Finally, the chapter will conclude with a discussion of future directions for research arising from the study.

9.2 CONCLUSIONS

9.2.1 General Research Findings

In order to provide a basis for a discussion on the research findings, it is useful first to briefly review the contribution of each chapter to this dissertation. To put this review in context, a diagram summarising ISSAM is presented in Figure 9.1 to make explicit the dissertation references concerning each ISSAM component. A brief summary of each chapter will now be presented with references to Figure 9.1 given where appropriate.

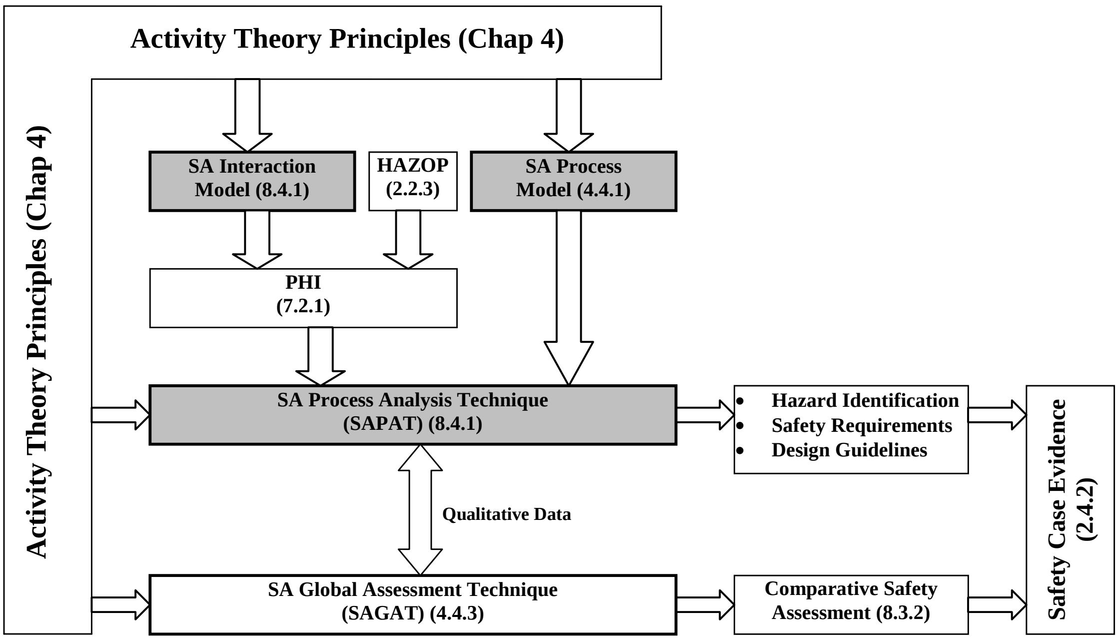


Figure 9.1 - Dissertation Review

Chapter 1. In Chapter 1, the intended area of research was introduced with a discussion concerning the problems associated with the development of complex, interactive systems. The chapter also contained a statement of the aim of this dissertation together with the objectives that would need to be achieved to fulfil the aim. The aim and objectives will be reviewed in section 9.2.3 when a detailed evaluation of this research is presented.

Chapter 2. Chapter 2 introduced the main concepts associated with safety in the context of complex, interactive systems. The chapter also provided definitions for the safety terminology used throughout the remainder of the dissertation. Figure 9.1 shows how the discussions in this chapter concerning the HAZOP technique and the generation of safety case evidence were directly relevant to ISSAM.

Chapter 3. This chapter undertook a critical review of SA before proposing a Situated Cognition perspective of SA. The Situated Cognition perspective encapsulates the themes of, Awareness (the product of SA), Situated Action (the process of SA), Context and Dynamism which were synthesised from the dominant theoretical perspectives on SA. The chapter also presented a review of the general methods available for the evaluation of SA in context. The review concluded that SAGAT would be suitable for the evaluation of the SA Product; however the lack of suitable SA Process models and analysis methods was recognised.

Chapter 4. This chapter contained the rationale for the selection of AT as an appropriate research method for this dissertation. The chapter contained an introduction to AT including an explanation of the structure of activity and the six main AT principles. The chapter then proposed an SA Process Model and showed how the model was consistent with the principles of AT. From this discussion, an initial SAPAT was developed and it was proposed that SAPAT and SAGAT could be integrated together to form ISSAM. Figure 9.1 shows how the discussions in this chapter concerning AT, the SA Process Model, SAPAT and SAGAT were directly relevant to ISSAM.

Chapter 5. This chapter examined the criteria for selecting a suitable system and developing an appropriate field study to achieve the aim and objectives of this research. The UKADGE system was then introduced before a discussion was presented on the suitability. The chapter also contained a discussion on the preconceptions and expectations of the researcher to minimize any interpretation bias during the data analysis phase.

Chapter 6. This chapter described the activities and conditions during a Pilot Study and a main USSS. The Pilot Study confirmed the suitability of UKADGE as a complex, interactive system and three Air Defence scenarios were identified as a suitable basis for SAGAT simulations. The chapter then described the detailed activities undertaken during the USSS Scenario Development and Simulation phases.

Chapter 7. This chapter explained how the ISSAM approach to interaction safety analysis was used during the USSS to analyse and interpret the resulting data. The chapter highlighted the practical limitations of ISSAM which were discovered during the USSS. A requirement was identified to modify SAPAT to include a PHI stage to enable the technique to focus on the hazardous system interactions. An explanation was given on how a UKADGE SA Interaction model was developed during the USSS and applied as part of SAPAT. Figure 9.1 shows how the discussions in this chapter concerning the PHI technique and the SA Interaction Model were directly relevant to ISSAM.

Chapter 8. This chapter presented an appraisal of ISSAM and an explanation on how the method was modified to address the shortcomings identified in Chapter 7. The chapter examined the practical application of ISSAM and how the method could be used to collect safety data during the entire system life cycle. The chapter also explained how the ISSAM data could be used as evidence for safety cases from the SAPAT-based hazard identification, design guidelines, safety requirements, and the SAGAT-based comparative system safety assessment.

Having briefly reviewed the specific issues addressed by each chapter in this dissertation, the remainder of this section will summarise the findings of this research in the context of safety and SA. The findings of this research have been the presentation of empirical evidence to show the problem with usability metrics in safety-related systems and the validity of specifying SA as a measure of interactive system safety. These issues will now be examined in more detail.

Safety and Usability

Design metrics are often used when there is a requirement for progressive improvement and this dissertation has discussed how an increasing emphasis is being placed on usability metrics for evaluating the design of interactive systems. It was argued that an intuitive assumption often associated with usability is that an improvement will inevitably enhance system safety. However, observational and interview data from the USSS have demonstrated that safety and usability can, in some contexts, be mutually exclusive properties in systems that rely on SA for safe operation. These findings confirm that different methods and metrics are required for evaluating safety. It has been demonstrated that it is more appropriate to quantify safety in terms of the level of SA acquired through the system interactions.

It is entirely possible that making an interactive system safe will entail many trade-offs with usability. For example, the USSS revealed that a complex ICCS keying sequence could easily be replaced with a macro facility allowing a function to be invoked with a single key press. While this function may enhance system usability, it could inadvertently affect the safety of the system as a hazard can be associated with some of the functions being invoked. While a complex sequence may not be very efficient in terms of usability, it provides a number of opportunities for the operator to become aware that the function being invoked may be hazardous in the current context. It is not enough to simply concentrate on the usability of an interactive system to assure functionally safe operation.

ISSAM was developed in response to this problem. ISSAM provides the SA Process Model and SAPAT as a systematic method for identifying and analysing situated interaction hazards. In general terms, ISSAM provides a system designer with a method of identifying when interaction safety should take precedence over usability. ISSAM can also offer the system developer guidance on the design of interactions to avoid the sort of hazardous interactions observed during the field study.

SA as a Measure of Safety

The previous discussion suggests that any design trade-off between usability and safety affect the reliability of the cognitive processes involved with acquiring and maintaining a safe level of awareness of a situation. If a well-intentioned system designer aims to develop a transparent interactions to enhance usability, the resulting automatic interactions may have an adverse effect on the awareness of the operator. This may also affect the safety of the system. Safety must be specified in quantifiable or measurable terms in a similar manner to usability to have practical application.

This research has demonstrated that SA is a suitable attribute to specify for the quantification of the safety of the interactions in complex systems. Having suggested SA as a critical attribute for interactive systems, ISSAM was developed to help academics and practitioners to quantify this important phenomenon. This dissertation has presented a method of quantitatively assessing the contribution of the system interactions to the operator awareness.

9.2.2 The Contribution of this Dissertation

In the previous section, the high-level findings of the UKADGE field study were discussed. To have practical application to practitioners and academics in the field, it is necessary to demonstrate how the findings that were specific to the UKADGE study can be generalised. This discussion will therefore elaborate on the academic and practical contribution of this research and its applicability to people in the field. ISSAM was developed as a general method for analysing the safety of complex, interactive systems and this chapter will expand on the previous discussions to specify explicitly how ISSAM can be generally useful to both academics and systems development practitioners.

Activity Theory Applied

The dissertation has repeatedly discussed the limitations associated with the adoption of reductionism for studies of human cognition. Indeed, some of the field study findings discussed in Chapter 8 have demonstrated the lack of context associated with some methods compared to an AT approach. There are a number of different research approaches, such as Situated Action (Suchman 1987), Distributed Cognition (Hutchins 1995) and AT approaches, which consider the situated nature of human cognition and its associated activity. AT was chosen as the theoretical basis for this research as it was anticipated to be an appropriate research method for capturing the richness of human cognition in context. However, a major criticism levelled at the AT approach, even by its champions, is the difficulty of developing practical techniques and models based upon this theoretical stance (see for example Nardi 1996; Engeström 1987).

This research has adopted the principles of AT and applied them to the development of the SA Process Model and SAPAT. The SA Process Model and SAPAT have been applied during a significant field study conducted at four different sites over a period of 22 months between January 1998 and November 1999. In this way, this research has contributed to the academic field by addressing a major criticism of AT and applying the theory to a significant system study. It is not intended to imply that the adoption of AT was without its problems and a discussion of the difficulties is presented in section 9.2.3. Nonetheless, these research findings are grounded in AT and have contributed to the general methodological debate surrounding the practical application of AT to the analysis of complex, interactive systems.

A Situated Cognition Perspective of SA

This dissertation carried out a critical review of the literature relating to SA in Chapter 3. It can be seen from this review that there are merits in many of the competing perspectives of SA and the range of views that exists highlights the complexity of SA and the general immaturity of research in this area. The predominant Cognitive and Interactionist schools discussed in Chapter 3 both argue for the validity of their perspectives. From the cognitive view, the mental state of the user is important in trying to understand the awareness that the user builds up of a situation. However, from the Interactionist perspective, it is argued that only observable interaction data is available, tempting researchers to marginalise the mental state as a concern and focus on explaining SA without reference to the user's cognitive processes.

This research has developed a Situated Cognition perspective of SA which is synthesised from the Cognitive and Interactionist views. This Situated Cognition perspective encapsulates the equal importance of the process of acquiring situational awareness and the resulting state of awareness. The Situated Cognition perspective attaches equal importance both to the user's cognitive state and to the context or situation in which they are acting. From the research findings discussed in Chapter 7, the importance of situated cognition was emphasised by the observation that some interactions were only hazardous *in a specific context*. The Situated Cognition perspective reflects a move away from traditional information processing models of cognition towards the situated cognition (and situated action) perspective introduced in Chapter 2 as a developing movement in HCI. In this way, this research has contributed to the academic field by providing further evidence of the validation of situated research perspectives.

An SA Process Model

In Chapter 3, it was argued that operator SA is a critical system safety attribute which is acquired and maintained through a process of situated human activity. The chapter also discussed the theoretical limitations associated with the few models available to system developers for analysing the process of acquiring and maintaining SA. A requirement was identified for the development of an SA Process Model based upon the Situated Cognition perspective of SA.

This research has developed an SA Process Model and it was shown that the theoretical foundations of this model are consistent with the principles of AT. The structure of the SA Process Model represents the dynamic cognitive activities undertaken to acquire and maintain awareness when interacting with a complex system. The model partitions different areas of interest enabling system developers to consider the interaction boundaries between these partitions. The SA Process Model was applied to the analysis of an interactive system and it was used specifically for the analysis of human-computer interaction breakdowns and automatic interactions. This research has therefore contributed to the different scientific disciplines which deal with the phenomenon of SA through the generation and validation of a generic SA Process Model.

A Generic SA Interaction Model

In Chapter 7, a UKADGE specific SA Interaction Model was developed to show the human and technical UKADGE system functionality in terms of SA. This model was developed in response to a recognition of the need to identify and analyse only those interactions that are considered potentially hazardous from the large number of actual system interactions in a complex system. The UKADGE SA Interaction Model was developed specifically to facilitate a HAZOP-type analysis undertaken to identify SA-related system interactions.

For ISSAM to have general applicability, a generic SA Interaction Model was developed which uses the SA Process Model to represent the human factor. It was shown that the model represents the functionality of general interactive systems similar to the UKADGE system. It was shown that this model can be used as part of the ISSAM developed in this dissertation if the cost of applying ISSAM is justified (see the discussion on the limitations in section 8.4.2). Equally, the generic SA Interaction Model can also be used on its own to facilitate a HAZOP analysis for systems that rely on the accuracy of an operator's awareness for safe operation. This research has therefore contributed to the field of safety engineering by providing practitioners with a generic interactive system hazard identification model.

SAPAT Developed and SAGAT Adapted

The Situated Cognition perspective, developed during this research, encapsulates the equal importance of the process of acquiring SA and the resulting state of awareness. It was therefore argued in Chapter 2 that a comprehensive SA evaluation method must address both the product and process of SA. The discussion also indicated that SA analysis methods are available for evaluating the product of awareness while SA process analysis techniques are not generally available.

Endsley's (1995c) SAGAT technique was adopted as the most suitable method available for evaluating the state of awareness (the product of SA) of a system operator. However, the SAGAT version used in this research was adapted to be consistent with the AT approach advocated in this dissertation. An appraisal of the SAGAT method was undertaken and suggestions for future improvement to the SAGAT question compilation were given in Chapter 7. SAPAT was also developed and validated in this research for the analysis of the SA process. The development of these methods has contributed to practitioners and academics by providing an evaluation of SAGAT and the entirely new SAPAT technique which can be used to provide design guidance and safety assurance for interactive systems.

ISSAM

Finally, this dissertation has repeatedly discussed the difficulties associated with complex, interactive systems which present unique hazards and problems when developing safety-related systems. Chapter 2 presented a brief discussion on human factors which are repeatedly mentioned as the major contributing factor or even the direct cause of accidents or incidents. The discussion indicated that system developers often concentrate the majority of their efforts upon technical issues often neglecting human factors. As a consequence, technical hazards are relatively easy to identify with the many different techniques available. In contrast, human-related hazards are relatively difficult to analyse as there are relatively few techniques and methods available. The dissertation has identified a genuine and pressing requirement for the development of safety analysis methods that address the human factors in complex systems.

An Interactive System Safety Analysis Method (ISSAM) has been developed during this research as an integrated approach to the application of AT using SAPAT together with SAGAT as framework for evaluating both the process and product of SA. The initial ISSAM was developed through a field study of a complex, interactive system and modified to address the practical and theoretical shortcomings discussed in Chapters 7 and 8. Notwithstanding the limitations of ISSAM discussed in section 8.4.2, it was shown in section 8.3 how ISSAM can contribute to both the exploratory and confirmatory phases of a system's life cycle and also to the generation of safety case evidence to provide system safety assurance. From this discussion, it can be seen that the development of ISSAM contributes to both academics and practitioners in the field and it has contributed to fulfilling the requirement for safety analysis methods to focus on the human factor in complex systems.

9.2.3 An Evaluation of the Research

The broad aim of this research was to undertake an analysis of SA and to evaluate its relationship to complex, interactive system safety. It can be shown that the aim of this research has been achieved by fulfilling the specific objectives stated in Chapter 1:

Objective 1. Carry out a critical literature review to determine what situational awareness is and how it can be analysed and evaluated in a systems context.

A critical literature review was carried out in Chapter 3 and a number of major themes which are considered important were drawn from the review of the different theoretical perspectives on SA to form the basis of a Situated Cognition perspective of SA. From a Situated Cognition perspective, SA can be defined as *a measure of the degree of dynamic coupling between a* *user and a particular situation.* The Situated Cognition perspective recognises the equal importance of both awareness (the product of SA) and situated action (the process of SA) to a comprehensive evaluation of SA and the SAGAT and SAPAT approaches were developed and validated in this research to address these areas.

Objective 2. Identify and develop a suitable research method to frame an analysis of situated interactions and situational awareness.

The dissertation has highlighted the limitations associated with the reductionist human information processing paradigm which is the predominant cognitive approach. A number of new research approaches have been proposed that consider the situated nature of human cognition and action. AT was identified as an appropriate research method for this dissertation as it captures the richness of human activity through a research approach oriented toward studies of work in context. It is not claimed here that AT is *the* method for examining situated interaction hazards, however, this dissertation has presented a significant example of the application of AT to a research project. A more detailed critique of the use of AT for this research is presented below. From the AT perspective, the dissertation developed an SA Process Model and showed how the model was consistent with the principles of AT. An initial SAPAT, founded upon AT principles, was developed to frame a study of hazardous interactions through an analysis of the development of interactions within the hierarchy of activity.

Objective 3. Undertake a field-study of a complex, interactive system to analyse and evaluate situational awareness in context and to assess its contribution to system safety.

In Chapters 5 to 7, the dissertation presented a study of the UKADGE system and it was shown that this system fulfilled the criteria required to achieve the aim and objectives of this research. The dissertation has explained how the ISSAM approach to interaction safety analysis was used during the USSS to analyse and interpret SA in context and to assess its contribution to system safety.

Objective 4. Propose a general method for evaluating the safety of an interactive system in terms of its relative support for situational awareness.

The initial ISSAM was proposed in this dissertation which integrated the SAGAT and SAPAT approaches to the evaluation of SA through an analysis of operator awareness and situated action in context. The initial ISSAM proposal was applied to an analysis of SA in the UKADGE system and modified when found to be impractical or incomplete. An appraisal of the modified ISSAM was undertaken and a general evolution of the method was developed for the analysis of complex, interactive systems in context.

An Appraisal of AT

As discussed previously, AT has been criticised for the difficulty of applying the theory in practice. Despite this criticism, this research adopted AT as the theoretical basis for the development of the SA Process Model, SAPAT and also a variant of SAGAT which have been applied to a significant field study. An appraisal of the validity of ISSAM generated data was given in section 8.2 which showed that the data derived from the field study was consistent with the principles AT. Nonetheless, the adoption of AT for this research did raise a number of high-level issues and an appraisal of these will provide information which may help others to decide upon the suitability of this approach.

When adopting a particular theoretical stance for a research project, it is inevitable that the researcher will need to communicate ideas and principles to other academics to refine ideas and also when communicating with domain experts during a field study. One difficulty of applying AT was the communication problem associated with the terminology. For example, the differentiation between actions and operations has been shown to be significant in this dissertation yet the meaning of these terms is not self-evident. However, this problem is not unique to AT and the same criticism could also be levelled at the terminology used by other research approaches. The significant point is how much effort must be expended by the researcher to learn the terminology of one theory compared with another. In practice, it was found that the AT terminology and principles were not prohibitively difficult to learn and it is suggested here that that these are no more difficult than the terminology and principles used by other, similar approaches.

Finally, the term 'Activity Theory' itself can give the wrong idea. The name can give the false impression that AT is a behaviourist theory which deals only with observable activity while neglecting the cognitive state of subjects. However, this is not the case. This research has demonstrated how context rich observable data and interview data were both derived using the AT-based models and techniques. The findings have also shown how these different data sources were each integrated to support the other when, for example, observed actions were probed with focused questions to gain an understanding of the cognitive state of the subject. An important strength of AT compared with some other theoretical perspectives is that the theory directs researchers to integrate analyses of observable actions and cognitive states in the context of their environment. It should be remembered that Vygotsky's (1978) seminal book on AT was entitled, "Activity Theory: The Study of Higher Psychological Processes", which makes explicit the intended link between activity and cognition.

9.3 FUTURE RESEARCH ISSUES

It was pointed out in Chapter 5 that, within the realistic constraints of resources available for this research project, either a broad but shallow or a deep but narrow research approach can be taken. A deep but narrow approach was considered compatible with the aims of this research in order to provide a worthwhile contribution to the field and this has led inevitably to other issues which could be explored to develop this research. The primary areas for development arise from the limitations of ISSAM that were identified in section 8.4.2.

Risk Assessment

As discussed in Chapter 8, ISSAM does not deal directly with the concept of risk assessment, although the identification and analysis of interaction hazards is addressed. The principal mitigation that was offered for this omission is that previous attempts to quantify the probabilities and severities associated with the hazards arising from the human factors have been dominated by assumptions that apply to technical systems and often these do not translate to human systems. However, Chapter 2 examined the literature in this field and it was shown that current ‘best practice’ prescribes to the risk-based approach to safety management which has been advocated by the UK Health and Safety Executive and consequently has been adopted by many regulated sectors of industry throughout the UK.

It therefore follows that, in regulated industries, the application of ISSAM as currently proposed may need to be supplemented by other risk-based techniques to fulfil regulatory requirements. From this discussion, an obvious area for developing ISSAM would be the integration and validation of risk assessment techniques. However, this ideal must be balanced against a realisation that ISSAM-generated data offers significantly more than is currently available for the construction of safety arguments in regulated industries.

Simulation

In Chapter 2 it was shown that risk can be considered tolerable if it has been reduced to the lowest practicable level commensurate with the cost of further reduction. It was recognised that it would not be reasonable to apply ISSAM to the analysis of any system where the associated benefits in terms of risk reduction would not be cost effective. Clearly, the ISSAM approach is not practical to apply to simple systems when the risks are relatively small. For the successful application of ISSAM, a system must have the functionality available for high-fidelity simulations to be developed and exercised. The fundamental, theoretical approach advocated by AT, and by association ISSAM, is that the identification of hazardous interactions can only be meaningfully achieved in context. This presents a dilemma as the system must be installed with an advanced level of functionality for the simulations to be realistic and the ISSAM data to be meaningful. One area where this research could be extended to help to resolve this dilemma would be to develop a valid technique for the evaluation of the SA interaction process, perhaps using prototyping, at the earliest possible life cycle stage without requiring high-fidelity simulations.

Design Guidelines

This dissertation has presented a number of SA-related models, techniques and a method for the integrated analysis of safety in interactive systems. The application of these components has highlighted various interaction hazards associated with breakdowns and automated interactions. It was shown in Chapter 8 that the design of the system interactions can directly affected the potential for an action which was designed to be completed consciously to become an automatic operation and vice versa.

In Chapter 8, this dissertation offered some suggestions and general guidance to deal with these issues. However, this research has not fully developed specific design guidelines for dealing with hazardous breakdowns and automated interactions. Another obvious area of future work that would extend this research would be to prototype different interaction designs and from these develop some general design guidelines for interactive systems that rely on operator SA for the assurance of safety.

Analysis of Business-Critical Systems

Chapter 2 introduced the risk-based approach to safety advocated by the UK Health and Safety Executive. There are different types of risk than risks to the safety of a system. For example, a risk may relate to monetary losses such as those incurred in businesses that trade in stocks and shares. Modern traders rely on the decision making abilities of individual dealers that acquire their awareness by interacting with complex systems in a similar manner to an Air Defence Controller. This research has focused on the analysis of interactions which are hazardous to safety in complex, interactive systems.

Another area where this research could be extended would be to examine the application of ISSAM to the analysis of interactions that are financially hazardous in business-critical (as opposed to safety-critical) systems. It is envisaged that ISSAM could be used in this manner to evaluate these systems to identify and mitigate against the risks associated with hazardous interactions. It may even be possible to obtain absolute measures of SA with these systems using the SAGAT technique as, in business-critical environments, the questions would probably have objective and quantitative answers.

9.4 SUMMARY

The chapter began by briefly reviewing the aims and achievements of each chapter within this dissertation in order to set the context for the remainder of the discussion. This chapter also summarised the findings of the research undertaken for this dissertation in the context of both safety and SA. ISSAM was developed as a general method for analysing the safety of complex, interactive systems and this chapter has elaborated upon the previous discussions to demonstrate how ISSAM is useful to academics and systems development practitioners. This discussion has explicitly demonstrated the academic and practical contribution of this research to the field. The chapter integrated the theoretical conclusions of the literature review in Chapter 2 with the interpretations from the field study in Chapter 7 to demonstrate that the aim and objectives of this research have been fulfilled. Finally, the dissertation concluded with a discussion on future directions for research arising from this study.

For complex, interactive systems situated in dynamic environments, an operator must 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. This dissertation has argued that SA is critical to system safety and that it can be used to help to understand human cognition in context. The hazards associated with human failures are very different from those 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 of users. This research has investigated the affects of interactions on operator SA in order to assess their effect on the safe design of interactive systems. The broad aim of this research has been to undertake an analysis of SA and to evaluate its relationship to complex, interactive system safety. Through the development of ISSAM, this aim has been achieved.

APPENDIX A - PILOT STUDY QUESTIONNAIRE

INTRODUCTION

The aim of this questionnaire is to collect data concerning the ICCS Man-Machine Interface (MMI) and equipment reliability from a representative sample of fighter controllers. The questionnaire data will be analysed and the results will be used to evaluate the prototype UCMP MMI.

QUESTIONS

Name: Rank:

Brief Outline of Professional Experience:

"What 3 control scenarios would you use to evaluate the UCMP MMI on a single console?" eg: Tanking, 1 v 1 etc. These scenarios should stress the operator's mental capacity and require console interaction to the degree indicated.

High Workload Scenarios:

1.

2.

3.

Medium Workload Scenarios:

1.

2.

3.

Low Workload Scenarios:

1.

2.

3.

"What 3 control scenarios would you use to evaluate the UCMP MMI on multiple consoles with lots of interactions between operators?"

User-Interaction Scenarios:

1.

2.

3.

"Based on your experience, approximately how often did the following equipment fail when you were on console?"

Equipment	Total Failures/Month	Partial Failures/Month Affecting Task
DHS		
Radar display		
Voice console		
Master access switch		

"Please indicate of any sources of on-site data, such as records or documents, that may provide data on ICCS equipment reliability?"

Thank you for completing this questionnaire.

Please return the completed form to Flt Lt Carl Sandom by 1700 on 17 Feb 98.

APPENDIX B - USSS SCENARIO DESCRIPTIONS

TANKING SORTIE DESCRIPTION

Tanking involves usually one, but possibly more, tanker aircraft operating on an established racetrack within given height blocks within the bounds of a tanker refuelling area. Groups of receivers, typically from 2 to 8 aircraft per group, join with the tanker(s), under the control of a weapons controller, to receive fuel. This operation frequently results in many aircraft squeezing into a relatively tight space, and the maintenance of flight safety is more difficult, increasing in difficulty as more aircraft join the fray. The workload of the controller, and the interaction with the HCI, is increased during tanking sorties as compared to routine training sorties for 4 main reasons:

a. Sortie Administration. Sortie Administration is increased owing to the number of discrete groups involved in the operation. Each joining group of aircraft will require, as a minimum, the following administration calls on the ground to air communications: check in, identify, radar service, RPS, check mode 'C', set height, vector to intercept tanker, positional information on approach to tanker, positional information on other participatinggroups of aircraft, positional information of potentially conflicting non-participating aircraft, monitor the radio whilst tanking, set height on departure from tanker, handover on departure from towline. In addition, information must be passed to the tanker concerning who is joining the tanker and from where. When repeated for many groups this represents a vast increase in sortie administration and hence to the controllers general workload.

b. Landline Communications. The use of the landline communications is increased owing to the increased requirement for external liason as a result of the many handovers and takeovers that will be conducted (potentially one for each group of aircraft joining the tanker) during the course of the operation, and the coordination that will be required with the controllers of non-participating aircraft to preserve flight safety.

c. Ground to Air Communications. The use of ground to air communication is heavy owing to the number of aircraft on channel and the amount of sortie administration required to effectively control them as explained in paragraph 1a.

d. Track Management Overhead. The use of the HCI is increased considerably as a result of heavy track management overheads, heavy use of the range and bearing feature (track to track) and a heavy requirement for height checking via System Identification Facility (SIF) interrogation. SIF interrogation is required to identify the height and control agency of potentially conflicting non-participating traffic, and to monitor the height of participating traffic to ensure all groups are at their assigned heights, and maintain their assigned heights, throughout the operation in order to preserve mutual safety. Range and bearing, in conjunction with SIF interrogation, will be heavily relied on to provide all joining groups with accurate positional information of the tanker, of other participating traffic and of potentially conflicting non-participating traffic. Track management may require the controller to initiate tracks for joining aircraft, will require the controller to link all tracks to their respective mission and require them to manage these tracks throughout the time the aircraft are on channel; the latter will usually involve a considerable amount of track positioning. Owing to the number of aircraft involved there is a tendency for a large number of tracks to be displayed in a small area which can clutter the display. To maintain some sort of order to the display, tracks are usually cancelled when the aircraft join the tanker and reinitiated and linked upon departure, a practise which results in increased controller/HCI interaction.

The assistant's workload will also be high during tanking sorties with a commensurate increase in HCI interaction. Landline communications will be extensively used to liase both internally and with external agencies, and the console will be used extensively for the input and updating of missions for the tanker aircraft and the receivers.

2 v 2 SPLIT FREQUENCY SORTIE DESCRIPTION

Sorties involving a 2 v 2 split frequency mission require 2 controllers, one of which is nominated as the lead controller. The missions can be with Airborne Interceptor (AI) or non-AI equipped aircraft or a mixture of both types. The latter requires a much higher level of control until reaching visual acquisition of the target. The mission scenario is typically a split to some 45 – 50 nm to holding points until all parties are ready; the controllers then co-ordinate between each other to call 'fights-on' (see Transcription in Appendix D).

The lead controller has the extra burden of ensuring the merge occurs in an area free from non-participating aircraft; co-ordination can be imposed but removes the tactical freedom required for air combat. Furthermore, high-energy manoeuvres in air combat by definition mean that the aircraft are operating at the edge of the performance envelope eroding safety margins. Therefore, co-ordination is the least preferred option by both controllers and aircrew.

The HCI interaction will be heavy with SIF interrogations of participating and non-participating traffic with range and bearing facilities being in constant use for target information. In addition, both controllers will be interrogating any aircraft that may penetrate their imaginary safety bubble around the merge point. Any non-AI equipped aircraft add to the workload as they require a higher level of control and information flow.

The handover of aircraft post mission is likely to be fragmented as fuel usage depends on many factors and cannot be managed to the extent of routine sorties; aircraft may also return to base alone adding to the HCI and general controller workload.

COFFEE 'C' SORTIE DESCRIPTION

Coffee 'C' Exercises are conducted in an electronic warfare environment with the controller's radar and radio frequencies being subject to 'jamming' i.e. interference to radar picture or radio frequencies. The exercise is designed to train the controller to cope with the very demanding environment that an enemy would be expected to target against a command and control system. The Air Defence fighters allocated to the exercise are also subject to AI jamming which is also designed to replicate a wartime environment. For safety reasons these exercises are conducted under the lowest form of service by the controller who is also 'screened' by a safety controller working on an unjammed radar.

During these exercises the controller will be working very hard to try and detect the enemy aircraft simulated by specialist jamming aircraft and also 'silent', that is non-jamming, bomber or fighter bomber aircraft. The HCI interaction will be particularly heavy as the controller will be trying very hard to ascertain and maintain his situational awareness on a jammed radar and radio frequency. He will also have to interact with the reporting team to a much greater extent than his normal sortie workload. Overall, the controller will be working very hard to maintain situational awareness and many, on initial exposure to the exercise, reach data overload and fail to cope with the extra demands. For that very reason, the Master Controller and the training staff must graduate the exercise and slowly increase the workload for new and inexperienced controllers.

The takeover may be carried-out during a jammed environment so the controller may start at a point of disadvantage. Handover at the end of the sortie may not always be accomplished and the aircraft will recover visually.

1V1 BAT AND BALL SORTIE DESCRIPTION

Sorties comprising of non-Airborne Interceptor (AI) radar equipped aircraft such as the Hawk tend towards higher workload than those with AI equipped aircraft as the former require closer forms of control to within much shorter ranges (typically 2-4 nautical miles (nm)) of the target; they also require visual acquisition. The 1 v 1 Bat and Ball scenario involves 3 aircraft playing the interchanging roles of fighter, target and spare. The fighter is controlled against the target from a briefed distance (known as the split range and typically 25 –35 nm) with the spare aircraft in a holding pattern. With good planning, once the fighter has completed its mission against the target, the correct split range has been achieved between the fighter/target pair and the spare. The target from this intercept now becomes the fighter for the next, and is controlled against the new target which was previously the spare; the fighter now becomes the spare and enters a holding pattern.

For most sorties, once an intercept has been completed, the participating aircraft are separated into fighter and target and undergo a transit out to the required split range; this affords the controller some respite and a chance to plan for the next intercept and pursue any coordination which they deem necessary for safety against non-participating traffic. With Bat and Ball sorties the end of one intercept is followed immediately by the start of the next. The controller must plan and co-ordinate whilst giving the fighter instructions and information. The short split ranges involved mean that each intercept is relatively short. Target information, and quite possibly instructions to the fighter, are constant throughout, so ground to air interaction is high. A brief interruption to target information for a landline conversation to effect coordination may lead to a poor final intercept. To prevent this, the controller will be working hard to plan around non-participating traffic to keep coordination to a bare minimum. In busy airspace, HCI interaction will be heavy with SIF interrogations of both participating and non-participating traffic, and range and bearing facilities will be used constantly to ensure that both target information and positional information of non-participating traffic are as accurate as possible; this is particularly important for non-AI equipped aircraft. Lastly, there is a tendency for controllers to concentrate on the fighter and target during an intercept. This leads to the possibility of the spare not receiving adequate warnings of potential conflictions. The controller needs to concentrate on more than just one situation which is a contributary factor towards this scenario being high workload. The takeover at the start of the sortie and the handover at the end of the sortie should be routine.

ACMI SORTIE DESCRIPTION

Danger areas D316 and D317 encompass the Air Combat Manoeuvring Instrumentation Range (ACMI) typically used for groups of fighter aircraft to engage in air combat. Controlling these engagements, particularly when eight or more aircraft are involved (usually a 4 v 4 engagement but may be 2 v 6 etc), is invariably busy for the controller. D316 and D317 provide sterile airspace (free of non-participating traffic) within which these multi-ship engagements can be conducted more safely. However, the area is relatively small, and is bounded by busy airways and upper air routes. There are three distinct phases to these sorties, each of which presents its own challenge to the controller which in turn increase the interaction with the interface:

a. The Takeover Phase. The takeover of a fighter package of eight or more aircraft approaching D316/317 often involves heavy use of all HCI facilities. Landlines will be used to takeover the package from the transit agency, and will also be used to liase with external agencies for traffic information and co-ordination to maintain safety in the busy airspace surrounding D316/317. Initially, all participating aircraft are taken over by a single controller until the sortie admin has been completed; one of the two elements in the package is then handed over to the second controller. Ground to air communications are busy as eight or more aircraft call up on a single channel; the sortie administration for a sortie utilising the ACMI range is greater than that for other sorties as the special conditions which apply within the range are briefed to all aircraft. The interaction with the HCI is busy for both controller and assistant. The controller has 8 missions to link and track, will be interrogating the SIF of both participating and non-participating traffic and setting up the bullseye point from which most of the target information will be given. The assistant may have to create the eight or more missions, will be busy logging significant events on the log sheets and may be using the landline comms to obtain traffic information for the controller.

b. The Sortie. During the sortie it is not uncommon for aircraft to stray close to, and occasionally across, the bounds of D316/317 during large multi-ship engagements. This can make landline liason with other agencies frequent and hectic. Manual track management is often the only way to accurately track the plots of aircraft engaging in high energy manoeuvres. Combined with the constant use of the bearing and range facility to provide accurate target information on the four or more target aircraft, constant SIF interrogation to determine heights (and friend or foe once the participants have closed), heavy use of ground to air throughout for the considerable target information required and the shepherding the participants to keep the fight within the bounds of D316/317 all ensure that this phase also requires heavy controller/HCI interaction.

c. The Handover Phase. Handover at the end of the sortie is rarely quiet and straightforward. All aircraft should be taken over by a single sortie controller in preparation for handover of the whole fighter package to an external agency in preparation for the transit back to base. The hapless controller is now trying to join all 8 or more participants into a single formation ready for transit prior to exit from the range. This process is often achieved as the aircraft are streaming out of the range and into the busy airspace surrounding the range where non-participating traffic suddenly become a factor. In this case, use of the landlines for liason with external agencies for safety may be extensive. Heavy use of ground to air comms will be required to maintain mutual safety between participating aircraft, maintenance of safety against non-participating traffic and target information to participants to effect the join up of the group. If the fighter group decides to depart the range as fragments, handovers will be effected by the relevant controller. This situation usually arises as a result of individual aircraft running low on fuel during the fight and requiring individual departure and transit. In such cases, the handover is done whilst the main fight is still in progress.

APPENDIX C - TANKING SORTIE TRANSCRIPTION

TIME	COUNTER	ACTIVITY	INTERACTION
00:43		Not due 15-20mins	To WCA
		Squawks please sir?	From WCA
		2402/2403	To WCA
3:42		Sitrep	To IC6
9:32		Confirm NATO callsign	From IC6
		What position is Polecat?….IC8	To WCA
12:20		Blacksmith UHF Rx problem	From LEU
13:00		London Mil h/o request	From WCA
		Do we have VHF?	To FA
14:00		Hello London Tartan 31	From LATCC
		Change squawk 1510	To LATCC
14:50		Taratan 31 is identified	To LATCC
15:30		Blacksmith h/o Radar Information	From ScATCC
		Squawk 1516	To ScATCC
16:36		Tartan radio check	From Tartan
16:46		Blacksmith radio check	From Blacksmith
		Blacksmith remain 170 blocking 150-180?	From Blacksmith
17:16		Tartan ID RIS	To Tartan
18:36		Ever decreasing list: Blacksmith, Scimitar 1-2, RAFAIR 524, Zircon 1-3	From Tartan
19:40		Tartan happy to take bootleggers	From Tartan
		Sitrep on Rxs	To FAA
21:00		RAFAIR2 squawks 24-15/16/17/10 RIS	From FA
23:55		Blacksmith – Tartan RT	
25:25		Tartan 31 recycle squawk now 2410	To Tartan
26:50		Anyone been told about the levels yet?	To WCA
27:30		Tanker on 15 not 10	From FA
29:36		FM call warning & sitrep	From FA
30:31		Blocking advice	From FA
31:00		Tartan 31 towline 5, scimitar 20m W coming in 10 mins	From ScATCC
		FM RAFAIR freecall advice	From WCA
32:24		Scimitar info	From (MC)?
		Ok raidtrack around Tartan?	From WCA
33:15		Tartan 31 (confirm)?	From Tartan
33:24		Pickup FA 2 immediately	From WCA
33:31		LEU state 4 single recovery, let Blacksmith know & scimitar	From FA2
34:10		Blacksmith 1&2 now state 4	To Blacksmith
34:45		Squawks change Blacksmith to E3 now	From FA2
		We're looking for bootleg now with Blacksmith cancellation	Tartan
36:41		(Did you) ?	From FA
38:30		How many ac RAFAIR 524?	To Tartan
		4 in total RAFAIR + Zircon	From Tartan
39:35		Scimitar 1/2/3	From ScATCC
		Scimitar 1/2/3 go ahead	From Scimitar
		H/o scimitar	From ScATCC
		2416/160 call me tad 125 & 086	To ScATCC
41:05		Tartan 31 scimitar coming on now, W25M	To Tartan
41:30		Scimitar radio check	From Scimitar

TIME	COUNTER	ACTIVITY	INTERACTION
41:35		Scimitar ID RIS, tanker 090/20 FL170	To Scimitar
		Tartan – Scimitar RT	
42:33		Did scimitar 2 check-in?	From FA
42:40		Scimitar2 radio check	Scimitar2
43:30		Scimitar clear to join RT	
44:06		Spoken to scottish re:4635 NW is it Zircon Rx?	From FA
44:48		RO Tartan tracking, Scottish say Scimitar 1 still showing their squawk	From FA
45:20		Message Tartan tracks initated can't cancel down	To ROA
		Mass of pendings around Tartan can we get rid of these?	To RO
		RAFAIR A&D heading towards…	From FA
47:40		Tartan 31 Traffic alert FL310	To Tartan
47:51		Zircon might be RAFAIR 524 heads up	From FA
51:40		RAFAIR GR6 or 7	ToWCA
52:07		FA2 console frozen	From WCA
53:10		RAFAIR 524A & D just passed your squawks height block	From (inaudible)?
54:05		RAFAIR squawks?	To FAA
		Info on 6123 squawk… RAFAIR	
		Tartan – Scimitar RT	
55:30		Scimitar 3 h/o info	ScMil
		Scimitar squawk 4623	To Scimitar
57:45		Scimitar 3 contact ScMil	To Scimitar
58:45		Tartan 31 check Scimitar	To Tartan
1:00:10		Scimitar 1&2 coming off towline 5	To ScMil
1:00:59		Scimitar 1 clear tanker vector?	From Scimitar
1:01:10		Clear vector W	To Scimitar
1:01:32		Have you got Scimitars? No radar service available du to capacity	From ScMil
		Scottish problem happy with FIS?	To Scimitar
1:02:45		Scimitar 1 & 2 h/o 2146 squawk	To ScMil
1:03:42		Scimitar 1 squawk 2146	To Scimitar
1:04:15		Scimitar contact Scottish…	To Scimitar
1:04:50		RAFAIR update	From WCA
1:05:08		Tartan 31 any joy Blacksmith?	From Tartan
1:05:39		Scimitar coming back?…No	From Tartan
		Tartan 31 contact RAFAIR A & D	To Tartan
1:08:00		Ok to cancel Scimitar missions?	From WCA
1:09:50		Who's my FA?	Shout To FA
1:10:00		Tartan 31 willing to go off towline	To FA
1:10:30		Tartan 31 clear to S	To Tartan
1:11:18		Got to take control of 524a&d	To LATCC
1:11:54		RAFAIR 524 A& D h/o 2F3 RIS	From LATCC
1:12:50		RAFAIR 524 B h/o	From LATCC
1:13:54		RAFAIR A radiocheck	From A&D
1:14:19		Confirm FL160	Zircon
1:14:51		RAFAIR 524 B radio check	From 524 B
1:15:10		Tartan – RAFAIR RT	
1:15:12		(inaudible)????	????
1:15:35		Tartan 31 starboard 190	To Tartan
1:15:53		Distance?	From 524 B
		Tartan – RAFAIR RT	

TIME	COUNTER	ACTIVITY	INTERACTION
		RAFAIR A radio check	From 524A
1:17:41		524B recycle 2417	To 524B
1:18:07		524A sitrep on Tartan	To 524A
1:18:50		RA7 now active	From WCA
1:19:12		Tartan ready to continue alone?	To Tartan
1:19:20		524B sitrep Tartan	To 524B
1:20:20		524A sitrep Tartan	To 524A
1:21:00		524B sitrep Tartan	To 524B
1:22:27		Clear join RT	
1:22:49		Ok for Tartan to wander around a bit?	To FA
		Tartan – 524 RT	
1:26:12		Clear manoeuvre as required	To Tartan
1:27:43		524D looking h/o ScMil go LL	From 524
1:29:04		H/o heads up RAFAIR A/D/B 3GR7 5min, will they be coming off as 3 ship?	To ScMil
1:30:50		Tartan is 524 coming off as 3 ship?	To Tartan
		Affirm	From Tartan
1:31:05		Confirm	To ScMil
		4633	From WCA
1:31:35		Any bootleggers?..No	To FAA
1:32:36		Looking for bootleg eh? Happy going tactical	From FA
1:33:17		Tartan 31 just to confirm Area 4 not active	From Tartan
		Tell him no bootleggers clear RTB	From FA
1:35:05		Yawn	
1:37:28		When clear LT to base	To Tartan
		524ABD clear continue N	From 524
1:38:10		Roger FL145 a squawk 4633	To 524
1:39:25		Tartan LT now 170	To Tartan
1:39:59		Pos 3 for h/o	To ScMil
1:40:08		RAFAIR h/o	To ScMil
1:41:00		RAFAIR Contact ScMil	To RAFAIR
1:41:25		Tartan clear descend FL160	To Tartan
1:42:50		H/o Tartan 31	To ScATCC
1:43:19		Get Tartan check in TAD30	From WCA
1:43:30		H/o Tartan 31	To ScATCC
		Tartan squawk 2654	To Tartan
1:44:20		Tartan contact ScATCC	To Tartan
1:44:55		Endex	

APPENDIX D - 2 v 2 SPLIT FREQUENCY SORTIE TRANSCRIPTION

TIME	COUNTER	ACTIVITY	INTERACTION
	38	Skylark is airborne	
	148	RPS been updated	From WCA
	228	Controller 1 Neat Velox	To Mil ATC
	326	Velox ID ADIS	From AC
	350	Clear Op ADIS	To Velox
	366	Common Aux?	To Velox
	390	1046=Velox1, 5621=Velox2	To WCA
	428	Velox Neat confirm bullseye control?	To Velox
	448	Request height block 5000-FL300	From WC8
	466	Pass height change to 5000-FL300	To Velox
	474	Change height block (on EDDIE)	To WCA
	476	Were working same 5000-FL300	To WC8
	496	Ready to play?	To Velox
	504	5&6a active in block 5000-FL300	WC4
	513	Split range 33	To Velox
	522	Velox report if not ready	To Velox
	525	We are ready to play	From Velox
	529	Ringing WC2	
	539	Pick up Stef! (shout)	To WC8
	546	Fights on – Fights On	To WC8
	548	Fights on – Fights On	To Velox
	552	Velox, single group 4, south2 , manoevering	To Velox
	556	Setup again	From Velox
	562	Turn outbound starboard not long enough split	To WC8
	570	Resetting	To Velox
	584	Airspace tight advice	To Velox
	608	20-30min bootleg required?	From Velox
	632	Velox looking for bootleg RA6, liase direct IC4	To FA
	644	Splits 30…Turning cold	To Velox
	646	Copy	From Velox
	652	Confirm ready?	To WC8
	663	Fights on – Fights On	To Velox
	669	Single group 200/4, pair close cold, man 3 north	To Velox
	686	My height 24000, 200/2	To Velox
	709	Westpool??? 1 Hot West	To Velox
	710	Committing 275/3	From Velox
	712	Same	To Velox
(IP1)	**720**	**Traffic info 6021 please , NW Flan? heading SE**	**To WCA**
	725	????	From Velox
	737	Limit top block 23000 no option	From FA
		????	From Velox
	766	Formation widening	To Velox
		????? south	From Velox
	780	Same	
	786	Closing pair swept right south showing 1900	From Velox
	796	What is it?	From WCA
	808	Pair hot 245/17 swept left 3 indicating 19000	To Velox
	815	Copy	From Velox
	820-850	Formation widening…chasing Velox 2…Velox 2 off you onto 1	To Velox

	864	Targets 265/20	
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	866	Disregard about limiting height	From FA
(IP2)	**874**	**265/22, lead trail 3, left turn chasing Velox 1, strangers NW fight 15 FL235 through the fight**	**To Velox2**
	887	6021/NW fight, 235 pair jags RTB colt RIS	To WC8
	895	Fight merge 270/23 pair chasing Velox 1	To Velox2
	900	Split?	From Velox 2
	902	No just chasing Velox 1	To Velox 2
	906	Copy	From Velox 2
	910	Velox 2 look for 275/22	To Velox 2
	913	Tac?	From Velox 2
	914	Tac 0305 right turn pair	To Velox 2
	918	Angels heading?	From Velox 2
	920	9000 right turn E, 1 man right 1o'clock, 2 hard right turn towards, 9000, ½ 2 at 3, 12 o'clock at 5	To Velox 2
	932	Roger Tally 1 in my right 2	From Velox 2
	935	Further man crossing nose now range 3 right turn at 11000	To Velox 2
	940	Tally 1 engaging	From Velox 2
	942	Velox 3, 1 stranger 275/36 now S 235	To Velox 3
	950	Velox 2, merged rear man, lead nose at 5	To Velox 2
	955	Velox 2, kill on the rear man	From Velox 2
	958	Lead man nose at 5 running 2/3, right 1o'clock 4.5 closing	To Velox 2
	968	Kill the trailer	To WC8
(IP3)	**969**	**Terminate, terminate**	**From WC8**
	971	Terminate, terminate	To Velox
	973	Terminate 2	From Velox 2
	974	Terminate 1	From Velox 1
	976	Velox 2, stranger, tactical 275/8, pair similar type FL235 transiting area	To Velox 2
	984	Airfield states update	WCA
	1000	Velox 2, playmate 1, 285/37 W	To Velox 2
	1006	Affirm	From Velox 2
	1008	Traffic Info 6072/180 where going?	To WCA
	1037	Velox 1, playmate 2, 268/30	To Velox 1
	1040	Uzi asked confirm turned off Charlie?	FAA
	1058	Single F3, FL180, inbound Leeming	WCA
	1062	Coord Velox - Uzi	WC6
	1080	East Teeside, Rambo 2, climbing FL330, full height block.	To WC8
	1098	Velox stranger, similar types, 245/21 heading towards inbound Leeming FL18	To Velox
	1105	????	From Velox
	1108	Velox flight safety C check unless above 245	To Velox
	1111	????	From Velox
	1117	Split range is 33, call when ready W	To Velox
	1118	Velox 1, were ready	From Velox 1
	1124	Ready in W?	To WC8
	1135	Velox 1…hot and ready	From Velox
	1139	Acknowledged , Velox, targets W bull at 4, man no height	To Velox

	1148	Fights on – Fights On	From WC8
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	1151	Confirm Fights on – Fights On	To Velox
	1155	??? stranger 255/26 W 180	To Velox
	1166	Knock off 2xF2 from Velox 2 from stats?	WCA
	1178	Targets 340/4	To Velox
	1181	Contact, single ???	From Velox
	1183	Close pair, height 2000 man through N	To Velox
	1186	???340/5 Velox 1 off to N	From Velox
	1190	Want me to go S?	Velox
	1193	No I'll go S	Velox
	1204	Stranger clearing SW 4	ToVelox
	1218	Velox 3 singleton only	From Velox
	1219	3 same	Velox
	1221	Close pair, suggest poss height stack	To Velox
	1228	Velox???280/21000	From Velox
	1231	Neat same, flanking SW	To Velox
	1239	Beaming S	To Velox
	1240	Confirm targets?	From Velox
	1242	Affirm, close pair suggest height stack	To Velox
	1247	2100 on 1 ac only	To Velox
	1250	???Tally my nose 10 call pair	Velox
	1253	Same	To Velox
	1262	My nose 5	Velox
	1265	Formation widening	To Velox
	1266	London for Coord	From WCA
(IP4)	**1273**	**Cood not above FL290**	**From LATCC**
	1286	Control kill southerly Jags	Velox
	1288	Roger	To Velox
	1291	Kill southerly	To WC8
	1294	???	Velox1
	1295	??? nothing	Velox2
	1299	Merge 255/16 single N fight R3 poss dead man?	To Velox
	1307	Fox 1, Fox 2 kill remaining Jag	From Velox
	1308	Roger	To Velox
	1314	Velox 2 one man out your 8o'clock 4	To Velox 2
	1315	Terminate – terminate	From Velox
	1324	Standby	To WCA
	1324	Terminate acknowledged	To Velox
	1328	IC4, Velox still coming to tanker?	From WCA
	1335	Confirm have bootleg for Velox?	To IC4
	1343	Velox, Madras 44 can take you what time?	To Velox
	1343	Standby	From Velox
	1344	???	Velox
	1353	Bases green code Delta	To Velox
	1359	Height block another run FL290	To Velox
	1360	Copy with Tango 15mins	
	1366	Roger	To
	1370	15 mins	To IC4
	1373	Neat Velox, confirm tactical with Tango	From Velox
	1376	Tango N25, Nof53…running E-W	
	1382	What's that?	To WCA
	1386	Split 30 call when ready	Velox
	1387	????	Velox
(IP5)	**1401**	**Confirm comply with restriction 290 top level**	**To WC8**

	1415	Adjust height on Tote?	From WCA
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	1427	Neat Velox split range?	From Velox
	1429	Split range 35	To Velox
	1434	Fights on in W?…Negative still joining	To WC8
	1439	Uzi not ready still joining	To Velox
	1441	Copy	From Velox
	1443	Ack, split range now 40	To Velox
	1456	6153 squawk…Yeovilton	From IC?
	1469	How are we now?	To WC8
	1476	Fights on – Fights on	From WC8
	1478	Fights on – Fights on	To Velox
	1479	Fights On Velox	From Velox
	1480	Group bull 08/010 man, my gadget height 13-14000 through N	To Velox
	1494	????	From Velox
	1501	070/9 pair swept right 3, heading 26, 14-15000, 065/6	To Velox
	1518	Fox 2 contact, singleton same SW 18000	From Velox
	1522	Neat same, 2^{nd} man N that to W	To Velox
	1524	????070/2	From Velox
	1528	Fox??	From Velox
	1531	????	From Velox
	1536	Neat same	To Velox
	1541	Delay the sort	From Velox
	1542	Delay the sort	To Velox
	1556	Joining instructions for the Tanker-level and squawks?	To WCA
	1562	????crossing	To Velox
	1566	Neat ???	From Velox
	1567	Roger	To Velox
	1568	?????	From Velox
	1572	FL150 2442	From WCA
	1582	????Fox 1	From Velox
	1587	Trailer 230/6	To Velox
	1588	1o'clock slightly high on me	Velox
	1590	20 tally	Velox
	1591	Roger	To Velox
	1594	Sorted both Fox 1 leader	To WCA
	1599	2 Tally my man	Velox
	1603	2 Tally my man in a climb heading south	Velox
	1605	???Jag	Velox
	1612	Come on! - Fox 2 kill northerly!	Shout
	1615	Fox 2 kill man just gone through to the West - he's dead	To WC8
	1622	2s engaged??	From Velox
	1624	????	Velox
	1631	????	Velox
	1634	Fox 2 my man	Velox
	1643	Fox 2 terminate Jag	Velox
	1644	????Bastard	Uzi
	1648	Neatished terminate	From Velox
	1649	Terminate acknowledged Velox	From Velox
	1654	Terminate – Terminate	To WC8
	1658	Velox your intention now?	To Velox

(IP6)	**1660**	**Velox turning off and on route to tankers**	**From Velox**
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	1662	Roger - join up vector 360	To Velox
	1664	360 for Velox	From Velox
	1666	When we’ve finished with tankers can we come back to you.	From Velox
	1670	Roger what do you require?	To Velox
	1671	1 v 1	From Velox
	1679	Uzi 4 275/8	To Velox
	1679	Velox on route	To FA
	1682	No problem you pick that up same freqs	From FA
	1687	Velox on route to tanker for bootleg what’s your Uzis doing?	To WC8
	1694	Velox 1 crossing you slightly right range 3 miles crossing you is Uzi 1	To Velox
	1701	Neat standby???	From Velox
	1702	Roger that, climb FL150 to join tanker	To Velox
	1706	???Velox	From Velox
	1717	I’d like to hand over Velox now there just debriefing with Uzi…	To IC4
	1720	OK go ahead	From IC4
	1721	Velox 1 & 2……	To IC4
	1726	2442	From Velox
	1739	Maintain your heading…lead squawk 2442	To Velox
	1748	Say squawk for lead again?	From Velox
	1749	2442???	To Velox
	1752	Tactical 230 range 18	From Velox
	1756	Same and contact Neat TAD *****	To Velox
	1765	Go for 15 mile split	Velox
	1778	Can you break your pairing for me?	To WC8
	1786	Can you mission assign Velox for me?	From ?
	1794	Flight on this….	From WCA
	1794	I’ll be with you in a minute…	To WCA
	1804	**FADE & BREAK**	
	1823	Same as before just a 1 v 1 now	To WCA
	1867	Just coming off the tanker now	From IC4
	1890	Velox sound like their coming off	From ?
	1908	Here they come	To WCA
	1945	Neatishead Velox	From Velox
	1948	Velox, Neat you allocator me	To Velox
	1950	Request intentions now?	To Velox
	1951	1 v1 ACT…bullseye..	From Velox
	1958	Happy with same height block 5-300?	To Velox
	1961	Affirmative	From Velox
	1963	Roger, Velox 2 port 09	To Velox
	1966	????	From Velox
	1972	Velox 1 request charlie on you’ve got the Texaco due westerly 5 mile heading S	To Velox
	1974	Velox 1 ..charlie on and visual ???	From Velox
	1977	Roger	ToVelox
(IP7)	**1980**	**Controller please**	**To IC4A**
	1982	He’s doing a h/o with Madras at the moment	From IC4A
	1983	I want to turn towards Madras that’s the problem..OK	To IC4A
	1988	Velox starboard 280 not above 10000	To Velox

	1991	Velox Not above 10000	From Velox
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	1998	Still need missions flight	From WCA
	1999	Yeah, just doing them now	To WCA
	2005	Tankers in the process of being h/o to London so we'll just continue to wait and ask you to keep him clear to the SE..correction to the SW	To Velox
	2015	Neat Velox	From Velox
	2016	Go ahead	To Velox
	2017	Request the RPS ??	From Velox
	2019	Regional Humber 997	To Velox
	2020	997 set 1	From Velox
	2021	Want some more fuel does he Chris?	Shout from ?
	2023	No I've ducked underneath you mate!	Shout to ?
	2031	You've got me in trouble	From WCA
	2035	Yeah, you've got that selected look (prods EDDIE) and I can't get access. I need my MTD up please. Just take it off a second	To WCA
	2044	Split 25	To Velox
	2051	Split 30	To Velox
	2054	Velox 2 to 1	Velox
	2065	Neat acknowledged	To Velox
	2066	Go ahead	From Velox
	2066	Neat acknowledged TOFE (Taget Odds Fighter Evens to maintain separation)	To Velox
	2068	Split 35, Velox 2 clear starboard inbound, Velox 2 target split 35 clear starboard inbound	To Velox
	2074	???	From Velox
	2076	Velox 1 allocated single group bull 335/5	To Velox
	2081	Velox 1 when cleared…correction when hot E you're cleared all levels Tankers clearing to the SE	To Velox
	2086	Get my worms….	Shout
	2090	Target 355/4, man ..through S, gadget height aim to gain 16000	To Velox
	2100	One stranger Velox 1 275/43 indicating FL230	To Velox
	2105	Velox 1 contact north of bullseye	From Velox
	2107	Same hot SW	To Velox
	2109	????	From Velox
	2110	Roger	To Velox
	2118	Checks EDDIE & watch	
	2130	Target ??? onto S	From Velox
	2132	Neat same	To Velox
	2185	Target facing up W	To Velox
	2187	Turning	From Velox
	2193	Stranger NW of the fight 10 miles heading towards indicating climbing through 270	To Velox
	2196	Copied	From Velox
	2228	Strangers W of the fight 6 still climbing	To Velox
	2230	Roger	From Velox
	2272	Velox 2 to ???	Velox
	2299	Fox 1 called??	Velox
	2302	Velox terminate??	Velox
	2304	Neat terminate acknowledged, Velox 2 next fighter ??? 31	To Velox

	2307	???	Velox
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	2300	Velox 2 roger	
	2309	NW of you 30 miles, NW 30 miles	From ?
	2311	Contact	To ?
	2312	OK it's a Tornado going through ?? maintaing FL270	From ?
	2323	Console 14 coordination please	To LATCC
	2326	Allocator NEAT FM coordination please fighter controller 14	From LATCC
	2328	Coordination 6141 just N flanborough 10 miles	To LATCC
	2331	FL270 maintain to my Charlie 1	From LATCC
	2333	FL270..my 2411 &12 just NW of Silver	To LATCC
	2336	Contact	From LATCC
	2337	Not above FL260 until your clear	To LATCC
	2338	Not above FL260 until your clear, thank you controller 14	From LATCC
	2340	Velox 1 & 2 not above FL260 there is uncoordinated traffic approaching from the NW 20 miles	To Velox
	2344	Not above 260	From Velox
	2346	Split 15	To Velox
	2355	What did they say 6141 was Flight..one F3?	From WCA
	2356	Yes	To WCA
	2359	Requesting coordination of your track SE of Silver15 squawking 0164	To ?
	2363	0164 ??? 310	From ?
	2364	?? 2411/12 not above FL290	To ?
	2367	290 thank you	From ?
	2369	Its that one there (points at picture)	To WCA
	2376	Split 30	To Velox
	2385	Velox 1 ready	From Velox
	2387	Velox 1 clear port inbound	To Velox
	2389	Velox 2 when commit commit starboard ???? 193/9	To Velox 2
	2392	????	From Velox
	2393	Stranger traffic south for 10 Northbound FL23 starboard turn will take you clear	To Velox
	2396	Roger	From Velox
	2400	Velox 2 group bull 180/8	
	2404	????	From Velox
	2405	Man through N indicating 16000	To Velox
	2408	What's the squawk Flight on that ??? track?	From WCA
	2412	186/6 single hot W medium normal	To Velox
	2414	???	From Velox
	2430	??? 230/6 18000 ???	From Velox
	2433	Same	To Velox
	2461	Targets possibly accelerating decimal 86	To Velox
	2464	Roger ??? contact	From Velox
(IP8)	**2466**	**Not bad**	**Shout**
	2502	Have they called Judy or anything?	From FA
	2507	??? Terminate	From Velox
	2512	Neat terminate acknowledged	To Velox
	2513	Roger	From Velox
	2517	??? Velox 1 off to the W	From Velox

	2519	Velox 1 can you rollout 300 on ???	To Velox
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	2522	Rollout 300…	From Velox 1
	2424	2 out 07	To Velox 2
	2425	2	From Velox 2
	2529	Which fighter flight?	From WCA
	2538	Humbers changed on the regional	From WCA
	2539	OK..remind me on the hour	To WCA
	2557	Split 20	
	2560	Velox 1 starboard 3/30	
	2564	Starboard 3	
	2567	I've just told him I want him at 30 and he's gone out at 27 so the whole things still staying in the same place	
	2572	Velox 1 range at bull ??? 48 right turn coasting out at FL230	
	2576	Affirmative	From Velox
	2577	Split to 25	To Velox
	2587	Split 30	To Velox
	2588	Standby controller	From WCA
	2590	Velox ???	From Velox
	2592	Velox 2 clear port inbound	To Velox 2
	2593	2	From Velox
	2594	Velox 1 commit starboard single group 225/6	To Velox
	2595	Controller 2 London Mil I'm working traffic SE of f? 12 miles heading 060/6024…	From Lmil
	2600	Contact my guys just turning right turn hot east…	To Lmil
	2601	OK, I'm radio information in the climb to 29 maintaining heading going to 41 to do some dives over the sea are you maintaining ?? in the the Silver area?	From Lmil
	2606	Round about there…	To Lmil
	2608	I'll try to keep to the N, what are you blocking?	From Lmil
	2610	I'm blocking 5-13…	To Lmil
	2611	Ok thanks	From Lmil
	2612	Velox 2 contact 240/5	From Velox
	2614	Same hot W single	To Velox
	2615	????	From Velox
	2617	Same	To Velox
	2622	Velox clear the full height block, strangers clear.	To Velox
	2624	Roger	From Velox
	2627	Velox 2 targets ?? SW	From Velox
	2631	Neat shows same	To Velox
	2660	My gadget shows target climbing and accelerating	To Velox
	2662	??? Shows target 26000	From Velox
	2663	Same	To Velox
	2678	Keep an eye on that it shows 4633….that's er…Scottish…findout what it is	To WCA
	2684	Flair????	From Velox
	2685	4633 at 95	To WCA
	2699	RAFAIR 528 going to Bruggen	From WCA
	2724	How many runs so far 5th?… I'm knackered	To WCA
	2754	Coming up to the hour for RPSs	From WCA

	2755	Thanks, remind me at the split	To WCA
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
	2764	???	Velox
	2766	Terminate - Terminate	From Velox
	2767	Neat terminate acknowledged base is showing green code D	To Velox
	2777	Velox check intentions	To Velox
	2778	Velox	From Velox
	2779	Acknowledged … recovery at base please	To Velox
	2784	Velox looking for radar recovery and shortcut	From Velox
	2786	Roger confirm the level	To Velox
	2799	Neat intentions now 190 for recovery	From Velox
	2802	190 roger cleared FL190 at core level	To Velox
	2804	??? 190	From Velox
	2820	Velox 1 & 2 recycle mode Charlie	To Velox
	2831	Getting no mode C off these guys	To WCA
	2852	Velox confirm you mode C is on?	To Velox
	2853	Affirm	From Velox 1
	2853	Affirm	From Velox 2
	2856	No indications of mode C here …… ah!	To WCA
	2860	????	From Velox
	2861	Roger	To Velox
	2884	What range do I h/o at?	To WCA
	2893	Velox what level decending to?	To Velox
	2895	Gradual descent ???? altitude	From Velox
	2896	Roger	To Velox
	2906	Gradual descent stop FL50 radar coverage	To Velox
	2908	???? and Velox 2 will	From Velox
	2912	Acknowledged	To Velox
	2916	Velox strangers nose 15 man VFR indicate climbing through 2000 pair	To Velox
	2919	Roger	From Velox
	2937	Strangers nose 10 now decended back to 1000 no factor	To Velox
	2938	Velox contact???	From Velox
	2943	H/o Velox 1&2 please	To LEM
	2948	Go ahead	From LEM
	2949	080 Leeming 39 W 2411&12 …radar short pattern circuit	To LEM
	2965	Squawk 0413	From LEM
	2965	Standby	To LEM
	2966	Velox 1 squawk 0413 to standby	To Velox
	2968	Squawks coming down in descent passing 125 to FL50 my stop, 2F3s for radar short pattern, RIS	To LEM
	2975	Velox1&2 are identified contact base stud 5	From LEM
	2977	Stud 5 thank you controller	To LEM
	2982	Velox 1 & 2 base have you ID contact them stud 5, stud 5 over	To Velox
	2980	Velox confirm Neat out	From Velox

APPENDIX E - COFFEE 'C' SORTIE TRANSCRIPTION

TIME	COUNTER	ACTIVITY	INTERACTION
	49	Sitrep	Ac
02.38	173	Carbon 1&2 ID FIS	Ac
	191	Recycle squawks	WCA
	211	Carbon 1&2 recycle squawks	Ac
	226	Sitrep & top height 18000 advice	Tanker WC
04.04	263	3 Groups Sitrep to Carbon	Ac
05.16	337	Carbon Parrots Sweet	Ac
(IP1)	350	Why wrong order??	HCI
07.25	368	Advice	FA
08.45	390	Sitrep	Ac
10.25	466	Intermittent contact Sitrep	Ac
11.48	543	Sitrep	Ac
	617	Request info on ac h/o	Tanker WC
14.43	635	Sitrep	Ac
	677	Sitrep	Ac
	690	Glare on screen!	HCI
16.45	711	Neat new picture report	Ac
16.52	933	Start of strobe jamming	
	948	RPS update	FAA
	967	Possible contact	Ac
	981	2nd group cold	Ac
17.18	996	Hot group 'Hooters' 140/35	Ac
	1036	Assistant please	FAA
18.18	1046	Hot group suspect pair	Ac
18.48	1066	Allocated 1st pair	FA
19.35	1107	Audio jamming starts	
19.52	1112	Carbon, allocated group 165/25, hot med, jammers pair, exercise engage	Ac
	1130	Assistant please	FAA
	1143	Tankers got new task	Assist
	1157	Assistant please	FAA
20.58	1174	Jamming new picture report	Ac
	1238	RPSs updated	Assistant
22.25	1240	Leader jamming	
22.41	1253	Using Humber?	Assistant
	1284	Singleton..	Ac
	1346	225/30	Ac
	1369	Trailers 215/35	
25.24	1380	Input NTN 357	Assistant
	1405	235/35	Ac
	1410	????	Ac
26.10	1413	Tanker Block Advice	Tanker WC
	1417	????	
26.25	1425	Take Off missile tally	Assistant
	1428	Southerly pair 230/40	Ac
	1439	????	Ac
	1449	????	Ac
	1466	Carbon 1 releasing	Ac
(IP2) 27.46	1475	Another group in mate	FA
	1488	Southerly group 235/45	Ac

	1499	Carbon 1…	Ac
28.24	1514	Carbon 1 Fox 1	Ac
TIME	**COUNTER**	**ACTIVITY**	**INTERACTION**
28.34	1517	Suspect bombers engage	FA
28.45	1527	Are you Exercise?	IDO
	1533	Neutralise…	FA
28.58	1537	Engaging 2…	IDO
	1546	Neat Clara	Ac
	1554	????	Ac
30.43	1611	Music report required	MCA
	1640	Poss contact	Ac
32.38	1694	2 min warning h/o to tankers	FA
33.47		Assistant music report	MC Assistant
33.58	1750	Carbon new TADS	Ac
34.34	1776	Beatles, Beatles (Cut to 2nd Frequency)	Ac
(IP3) 35.04	1796	EDDIE Interaction breakdown	HCI
36.30	1851	Possible vampires	Tanker WC
		WAIT FOR REALLOCATION	
43.13	2116	Check States before ac comeback to me?	Tanker WCA
	2128	Ac on now	Tanker WC
45.10	2184	Freecall & Check state advice	Tanker WC
45.36	2206	Target NTNs?	FAA
45.54	2216	More splash info request	MC
	2246	NTN Info	FAA
47.58	2295	Jamming	
49.37	2356	Jamming	
	2449	FA shouting at Tanker WC	
(IP4) 55.15	2556	Carbon 1 coming off	Tanker WC
	2576	Strangers warning	Tanker WC
56.18	2593	Carbon 1 radio check	Ac
56.26	2597	State check Tiger Fast juliet	Ac
56.32	2601	Run in advice 4 bombers	FA
56.59	2616	Carbon reset cap	Ac
	2628	Carbon 2 set to depart advice	Tanker WC
57.45	2642	Further contact	Ac
57.56	2648	Carbon 2 radio check	Ac
(IP5)	2665	Emergency squawk warning	Tanker WC
58.29	2669	Carbon 2 reset cap	Ac
58.44	2676	Carbon 2 recycle squawk instruction	FA
	2684	Do your reset please	Tanker WC
59.00	2686	Carbon 2 recycle parrot request	Ac
59.18	2694	Squawk apology	Ac
59.30	2702	Carbon 2 coming now	Tanker WC
59.51	2714	Carbon leader	Ac
59.56	2717	Go	Ac
60.01	2720	Comms are gone	
60.68	2760	Evacuate upper ops	

APPENDIX F - USSS POST-VIDEO INTERVIEW GUIDE

1. INTRODUCTION

A briefing sheet and video will be presented to the controller prior to the interview.

Explain that HQ 11/18Gp ASSU are undertaking an HCI Safety Study (HSS) on behalf of MOD(PE). Also explain that it would be helpful to the interviewers if the interview could be video recorded and transcribed at a later date to prevent any relevant information being overlooked.

Explain that it will take between 2 - 3 hours to conduct the interview and present them with the structure of the interview as follows:

- Introduction
- Personal Details
- Post-task Video Analysis
- Structure High-Level Activity
- Identify Critical Interaction Points
- Probe Each Critical Interaction Point
- Awareness Assessment
- Debrief

The interviewer will recap the following points with the controller:

- The overall aim of the HSS:
- To provide an evaluation method and benchmark data for assessing the safety of the existing ICCS HCI for later comparison with the UCMP HCI.
- The specific aims of the video debrief are as follows:
- To identify those human-computer interactions which are seen as safety-significant (ie: those that contribute to situational awareness) to the AD sorties.
- To identify safety-significant interaction breakdowns in the sorties.
- To explore how interactions are affected by operator situational awareness and HCI Usability.

2. PERSONAL DETAILS

Name: Rank: Specialisation:

Description of the Control Task:

Years in RAF:

Brief Outline of UKADGE Experience:

3. POST-TASK VIDEO ANALYSIS

Structure High-Level Activity

- High-Level description of sortie.
- Produce an activity structure diagram for this sortie showing:
- Objective
- Others involved
- Mediating tools used

Identify Critical Interaction Points

Explain that safety-significant interaction points are those critical points in a sortie when the controller makes decisions based upon their awareness of the situation. These points may be characterised as involving:

- High SA required
- High workload
- Critical decisions

Explain that we must identify and agree approximately 4 - 6 critical interaction points in the video of their sortie.

- IP1 =
- IP2 =
- IP3 =
- IP4 =
- IP5 =
- IP6 =

Probe Each Critical Interaction Point

Explain that the interviewer will ask a series of questions concerning the agreed interaction points that occurred during the task.

Situational Awareness

- Objects Contributing to SA (Sample Situation)
- *"List all the items of information which contributed to your awareness at this point?."*
- *"Which information was available through the interface?"*
- *"Which information was available from other sources?"*
- How awareness modified or not (Modify Awareness)
- *" Did this information lead you to modify your awareness or not?*
- *"Was any information rejected or was there any other information that could have helped you had it been available?"*
- Influence on next sample (Direct Consciousness)
- *"How did your awareness at this point direct your subsequent actions?"*
- *"How did your interaction with other people directly or indirectly involved in the sortie direct your subsequent actions?"*
- *"How did your previous training direct your subsequent actions?"*

Usability of HCI

- Effectiveness
- *"How does the interface support the accuracy and completeness with which you completed your goals?"*
- Efficiency
- *"How does the interface support the accuracy and completeness of goals in relation to resources expended?"*

Perceived Safety Implications

- Error Types
- *"What possible interaction errors could have been made up to this point?"*
- *"Would these errors be skill/rule based slips or knowledge based mistakes?"*
- Failure Modes
- *"What are the possible failure modes associated with the errors?"*
- Failure Effects
- *"What would be the severity of each interaction failure at this point?"*
- Protection Measures
- *"What possible protection measures could be provided against these errors?"*

Ask if there are any other comments:

4. ACTIVITY-BASED AWARENESS ASSESSMENT

SITUATIONAL AWARENESS

What do you think is meant by the term Situational Awareness?

Briefly describe what sort of mental construct you use to represent your awareness of the air picture when controlling?

Safe controlling relies on accurate situational awareness	never always 1 2 3 4 5

General

ICCS HCI supports the development of situational awareness	never always 1 2 3 4 5
Situational awareness is enhanced by the EDDIE	never always 1 2 3 4 5
Situational awareness is enhanced by the ITD	never always 1 2 3 4 5

Situational awareness is enhanced by the TTD	never	always
	1 2 3 4 5	

Alarms

Alarms are safety related	never	always
	1 2 3 4 5	
It is clear which alarms are safety-related	never	always
	1 2 3 4 5	
Alarms require operator action (apart from just cancelling)	never	always
	1 2 3 4 5	
Alarms break your concentration	never	always
	1 2 3 4 5	
Alarms are necessarily intrusive	never	always
	1 2 3 4 5	
Alarms messages are	clear	confusing
	1 2 3 4 5	
Dealing with alarms is	difficult	easy
	1 2 3 4 5	
Alarms are ignored in emergencies	never	always
	1 2 3 4 5	

USABILITY

What do you think is meant by the term usability?

Effectiveness

Interacting with the ICCS HCI is automatic	never	always
	1 2 3 4 5	
Interacting with the ICCS HCI requires conscious thought	never	always
	1 2 3 4 5	

Efficiency

The ICCS HCI causes too many distractions from controlling	never	always
	1 2 3 4 5	
The ICCS HCI requires too many switch actions	never	always
	1 2 3 4 5	
Making interaction errors with the ICCS interface is	difficult	easy
	1 2 3 4 5	

SAFETY

General

ICCS interaction errors can result in hazardous situations	never				always
	1	2	3	4	5
It is made clear which interactions are safety-significant	never				always
	1	2	3	4	5

Error Prevention and Correction

The system validates inputs before processing	never				always
	1	2	3	4	5
The system clearly and promptly informs the user of errors	never				always
	1	2	3	4	5
Safety-significant commands are verified before processing	never				always
	1	2	3	4	5

5. DEBRIEF

The subject should be given the opportunity to ask any questions or add any extra information deemed relevant.

APPENDIX G - TANKING SIMULATION SCRIPT

SIM TIME OR EVENT	EC01	TRACE NO.	TD01	TD02	DETAILS	COMMENTS
0215.00	Initialize Tartan 15, allocate to TD01	15	changedata trace 11 squawk 6151 mode C on		Position in wash crossing coast heading 070, speed K320, height FL201	
0219.00	Call BU WC01 for handover tartan 15	15				
0219.30		15	Call up BU WC01			
0220.00	Initialize blackcat 1&2	11 12			Heading 080, speed K350, height 100.	2nd receivers for tanker, Jaguars
0224.00	Initialize Scorcher 1&2, allocate to TD02	01 02		changedata traces 01/02 mode 3A as requested mode C on	Position 40nm SSW of DGR heading 020, speed M075, height FL160.	1st receivers for tanker, F3s
0225.00	allocate blackcat to TD02	11 12		Blackcat 1&2 change data Mode 3A 7000, Mode C on.		

SIM TIME OR EVENT	EC01	TRACE NO.	TD01	TD02	DETAILS	COMMENTS
0226.00				Scorcher 1&2 call BU WC01, both squawk 1511	Request 2.5 tonnes each. Pass departure brief: depart with London Military NW for Leuchars at FL210.	
0234.00		01		scorcher 1 announce PAN for left engine flame out, abort tanking and prepare for departure. Changedata mode3A 7700.		
0234.30				Blackcat 1&2 call BU WC01	Request 2 tonnes each. Pass departure brief: head west for the ranges VFR at 6000'.	
0235.00	**FREEZE**					Probe questions
0236.00		01 02		Scorcher 1&2 call departing	Request direct track CY with BU for direct handover to CY.	
0244.00	initialize RAFAIR 521A, allocate to TD01	21	changedata mode 3a 6112, mode C on. Turn right 360.		Initialize at MC 6 heading 340, speed K450,height 310.	3rd receiver for tanker, Harrier.

SIM TIME OR EVENT	EC01	TRACE NO.	TD01	TD02	DETAILS	COMMENTS
0244.10	Call BU WC01 for handover of RAFAIR 521 A&B					
0244.50		21	RAFAIR 521A call up BU WC01. Changedata mode 3A as required.		Request 1.5 tonnes. Pass departure brief: Climb FL 310, head SW with london military for Cottesmore.	
0245.00	**FREEZE**					probe questions
0250.00	Initialize Blackcat 3&4 and allocate to TD02	13 14		changedata mode 3A 6121 mode C on climb to FL150. Turn left 020.	position at coltishall heading 090,speed k350, .height 2000’.	4th receivers for tanker
0251.00	Handover Blackcat 3&4			After handover, blackcat 3&4 call BU WC01.	request 2.5 tonnes each. Pass departure brief: head NW VFR FL150.	
0252.00		11 12		Blackcat 1&2 depart	request heading 270 VFR descent to 6000’ rps	
0253.00	Initialize Razor 1&2	01 02			Initialize at LI heading 100 speed M075 height 030	
0255.00	**FREEZE**					probe questions

SIM TIME OR EVENT	EC01	TRACE NO.	TD01	TD02	DETAILS	COMMENTS
0300.00		21	RAFAIR 521A depart		Depart climb 310 head 260 handover london mil for transit to Cottesmore	
0301.00	Allocate Razor 1&2 to TD02	01 02		Changedata mode 3A 7000, climb FL150, mode C on		
0303.00			manual input update BZ weather to colour state yellow			
0304.00				Razor 1&2 call BU WC01	request 2 tonnes each. Pass departure brief: handover london military for transit to Leuchars FL230.	
0305.00	**FREEZE**					
0312.00	Initialize giant 1&2 and allocate to TD01	11 12	Change data to squawk 7000, climb to FL150 mode c on		Initialize position just W MC9 heading 280, speed K350, height 060.	
0313.00			Giant 1&2 call BU WC01		Request 1.5 tonnes each, pass departure brief: Head NW for the LOTAS VFR low level.	

SIM TIME OR EVENT	EC01	TRACE NO.	TD01	TD02	DETAILS	COMMENTS
0315.00	initialize stranger and allocate to TD02	37		changedata mode 3A 7000	Position 10 nm south of DGR heading 040 height 6000' speed K350	
0317.00		15	Tanker changedata mode 3A 7600			
0318.00		37		changedata height 240 gate climb rate		
0319.40		11		changedata mode 3A 7700		
0320.00	**FREEZE**					probe questions

APPENDIX H - 2V2 SIMULATION SCRIPT

SIM TIME OR EVENT	EC01	TRACE NO.	TD01	TD02	DETAILS	COMMENTS
0114.00	initiate scorcher 1 & 2 and assign to TD01	11 12	See details		Heading 120, height climb from initial height 010 to 160, speed 350 kts, Mode 3A 6141 with mode C on (only lead to squawk), TYCO K44+8 TF45.	2 F3s airborne from CY, initial fighters
0115.00	Initiate scorcher 3&4 and assign to TD02	13 14		See details	Heading 140, height climb 1000' to 6000', speed 350 kts, Mode 3A 7000 with mode C (lead only), TYCO K44+8 TF 45.	2 F3s airborne from CY
0130.00	H/O 1&2 to BU WC01					WC takes H/O of 1&2 from External Agencies as London Military.
0131.00			1&2 call BU WC01 on handover.			
0132.00				3&4 Freecall BU WC01		WC takes control of 3&4
1 min after all units on channel **0135.00**	**FREEZE**					Probe questions
0145.00	**FREEZE**					Probe questions
0200.00	**FREEZE**					Probe questions

SIM TIME OR EVENT	**EC01**	**TRACE NO.**	**TD01**	**TD02**	**DETAILS**	**COMMENTS**
0215.00	**FREEZE**					Probe questions
						Emergency.
0228.00				3&4 Recover VFR	Head towards CY, set height 6000’,	
0229.00	T/O 1&2 as London Mil		1&2 H/O London Mil		Head North for AARA 8, FL150, 300kts, squawk 6141 with ‘C’.	
0230.00	**FREEZE**					Probe questions

APPENDIX I - COFFEE ‘C’ SIMULATION SCRIPT

SIM TIME OR EVENT PROMPT	EC01	TD01	TD02	DETAILS	COMMENTS
032000		Carbon 1&2 from Conningsby		Give Weapon States, ask FIS	Block SL - 245
032000			Scimiter 1&2	Give Weapon States, ask FIS	Comms degraded 50% once jamming starts
033000		Handover		K44+8 TF45	
033200			Call up		
040000	Initiate stranger at Mullet				
040200	Input weather changes			CY Weather to Green	
042200	Initiate TOG Change			CY TOG to 1150kg	
042300	Stranger emergency				
042400	Friendly emergency			Scimiter 2	Squawk 7600
042500	**STOP**				

APPENDIX J - TANKING SAGAT QUESTIONS

FP	FP Description	Q No.	Question	Tolerance	Answer
A	023500 sim time	**1**	What is the mode 3C of Scorcher 1&2?	nil	
		2	What is the mode 3C of the 4 ship of strangers 10nm west of AARA8?	nil	FL250
		3	What is the mode 3C of the Tanker?	nil	FL201
		4	What are the mode 3A of Scorcher 1&2?	nil	7700 and 1562
		5	What is the heading of Blackcat 1&2?	+/- 10^{o}	
		6	How long before the stranger at UNI with mode 3A 5050, at its current speed and heading, reaches the boundary of AARA8?	+/- 1 min	
B	024500 sim time	**1**	What height are the pair of strangers manoeuvring at TOPPA?	+/-5000’	Unknown
		2	What is the height the 0370 squawk north bound on UM604?	+/-5000’	FL330
		3	What is the height of the 4347 squawk in the SW corner of AARA 8?	+/-5000’	FL025
		4	What is the airfield colour state at CY?	nil	
		5	What is the range of RAFAIR 513A to the tanker?	+/- 5 nm	
		6	What is the height difference between RAFAIR 513A and the tanker?	+/- 500’	

FP	FP Description	Q No.	Question	Tolerance	Answer
C	0255.00	**1**	What is the height of the stranger approaching from the east (actual position 10nm NW of TOPPA)?	+/-5000’	FL75
		2	Who would contact to co-ordinate this stranger?	nil	No one, no mode 3A.
		3	What is the height of the 0374 squawk southbound on UM 604?	+/-5000’	
		4	What is the height difference between Blackcat 3&4 and the tanker?	+/- 100’	
		5	What is the range from Blackcat 3&4 to the tanker?	+/- 5 nm	
		6	There is a pair of strangers approaching AARA8 to the NE. What is the range of these strangers from the tanker?	+/- 5 nm	
D	030500 sim time	**1**	What is the height difference between the tanker and the aircraft just turning away from AARA8 to the SE?	nil	
		2	What is the heading of the aircraft 5nm NW of DOGGA?	$+/-40^{o}$	080
		3	What is the height difference between the stranger within the lateral bounds of AARA8 and the lowest stacked receiver?	+/- 500’	
		4	What is the range from Razor 1 to the tanker?	+/- 5 nm	
		5	What is the airfield colour state at Leeming?	nil	Yellow
		6	What is the remaining give away fuel of the tanker?	+/- 100 kg	

FP	FP Description	Q No.	Question	Tolerance	Answer
E	0320.00	**1**	What is the height difference between Giant 1&2 and the stranger orbiting within the lateral limits of the southern part of AARA8?	+/- 500’	
		2	What is the height difference between the VFR stranger in AARA8 and the tanker?	+/- 100’	
		3	What is the range of that stranger from the tanker?	+/- 5 nm	
		4	What is the mode 3A of the tanker?	nil	7600
		5	Which other aircraft has an emergency?	nil	Giant 1
		6	What is the mode 3A of giant 1?	nil	7700

APPENDIX K - 2V2 SAGAT QUESTIONS

FP	FP Description	Q No.	Question	Tolerance	Answer
A	sim time 013630	**1**	How many strangers are in the ADS3 PI area within your height block (SL-350)?	nil	2
		2	What is the weapon/fuel state of Scorcher 2?	TF +/- 5 mins	K22+4 TF 40
		3	What agency is controlling the stranger 13nm NE of Coltishall?	nil	
		4	What is the mode 3C of Scorcher 3?	nil	FL258
		5	What is the mode 3C of the stranger in your PI area on upper air route UM604?	nil	FL330
		6	What is the mode 3C of the 2114 squawk NE of Redper heading SW?	+/-1000'	FL270
B	sim time 014500	**1**	What is the weapon state of Scorcher 1?	nil	K34+7
		2	What is the mode 3C of the 2114 squawk NE of Redper heading SW?	nil	FL180
		3	What is the mode 3C of Scorcher 2?		FL118
		4	What is the heading of the 6111 squawk?	+/- 10^{o}	180
		5	What is the mode ‘C’ height of the stranger on upper air route UL603?	nil	FL310
		6	What is the mode 3C of the 4324 squawk overflying the southern part of the helicopter corridor heading NE?	nil	FL080

FP	FP Description	Q No.	Question	Tolerance	Answer
C	sim time 020000	**1**	What is the fuel/weapon state of Scorcher 2?	+/- 5 mins	K22+4 TF 15
		2	What is the airfield weather state at CY?	nil	Green
		3	What is the FOG at CY?	nil	1050Kgs
		4	Of the 3 strangers to the NE of your area, what is the mode 3C of the pair heading 280?	nil	FL230
		5	Of the 3 strangers to the NE of your area what is the heading of the stranger with mode 3C of 250??	nil	180
		6	What was the FOG at CY before it changed?	nil	650kg
D	sim time 021540	**1**	What is the mode 3C of the VFR track to the north of the area heading 280?	nil	FL130
		2	What agency is controlling the pair of strangers to the west of the area?	nil	None
		3	What is the mode 3C of the pair of strangers to the west of the area?	nil	FL060
		4	What is the height of the 0363 squawk on upper air route UM604 heading N?	nil	FL370
		5	What is the weapon state of SC4?	nil	K33+6
		6	What is the approximate range of your closest ac to VFR stranger N of your area?	+/-5	

FP	FP Description	Q No.	Question	Tolerance	Answer
E	sim time 023000	**1**	Which of your aircraft has an emergency?	nil	Scorcher 3
		2	What emergency does Scorcher 3 have?	nil	Comms failure
		3	What is the approximate range of Scorcher 3 to CY?	+/-5nm	
		4	What is the range of your closest ac to the emergency squawk heading E in your area?	+/-3nm	
		5	What is the mode 3C of the emergency squawk heading E in your area?	nil	FL100
		6	What is the FOG for CY?	nil	900Kgs

APPENDIX L - COFFEE 'C' SAGAT QUESTIONS

FP	FP Description	Q No.	Question	Tolerance	Answer
A	T/O Scimitar 1 & 2 from London Mil (approx 034000 sim time)	**1**	What is the Mode 3C height of Carbon 1?	nil	
		2	What is the Mode 3C height of the stranger 10nm NE of SILVA?		FL250
		3	What is the Mode 3C height of stranger the heading SW on UL975?	nil	FL280
		4	Who is controlling the slow stranger 160deg, 25nm from SILVA	nil	
		5	What is the airfield colour state at CY?	nil	
		6	What is the weapon state and fuel state of Carbon 1?	NIL	K44=8 TF55
B	035500 sim time	**1**	What is the mode 'C' height of the 6131 squawk?	+/- 1000	FL330
		2	What is the weapon and fuel state of Scimitar 1?	nil	K33+6 TF30
		3	What is the mode 3C height of the 5267 SQUAWK 10NM West of Dogga?	nil	FL290
		4	What is the mode 3C height of the 2347 squawk at Otringham heading NE?	nil	FL290
		5	What is the mode 3 of the NW bound stranger at FAMBO?	nil	2447
		6	What is the heading of the 6150 squawk 25nm NW of FAMBO?	nil	090

FP	FP Description	Q No.	Question	Tolerance	Answer
C	041000 sim time	**1**	What is the Mode 3 'C' height of the VFR pair manoeuvring 15nm S of SILVA?	nil	FL150
		2	What is the mode 3A of the 2 strangers SE of FLAMBOROUGH?	nil	7000
		3	What is the airfield colour state at CY?	nil	Green
		4	What is the mode 3C of the 5144 squawk SE bound on UL 602?	nil	FL290
		5	What is the weapon and fuel state of Carbon 1?	nil	K33+6 TF10
		6	What is the Total On the Ground (TOG) at CY?	nil	900kg
D	042000 sim time	**1**	What is the mode 3C of the 2043 NW bound on UL602?	nil	FL260
		2	What is the mode 3A of the aircraft NE bound on UL975?		5022
		3	What is the weapon and fuel state of Carbon 2?	TF+/-5	K23+6 TF5
		4	How many target groups are there?	nil	3
		5	What is the position of Scimitar 1 from bullseye?	+/- 5nm	
		6	What is the heading of the VFR pair 10nm SW of DOGGA?	+/-20deg	350deg

FP	FP Description	Q No.	Question	Tolerance	Answer
E	043000 sim time	**1**	What is the TOG at CY?		1150kg
		2	What is the mode 3C of the ac 10nm NE of OTRINGHAM?	nil	FL060
		3	What is the mode 3C of the stranger in emergency?	nil	FL175
		4	What id the mode 3A of Scimitar 2?	nil	7600
		5	What is the airfield colour state at CY?	nil	Green
		6	What is the heading of the stranger in emergency?	+/- 10^0	130^0

APPENDIX M - USSS SIMULATION INTERVIEW GUIDE

INTRODUCTION

- HQ 11/18Gp ASSU are undertaking an HCI Safety Study (HSS) on behalf of MOD(PE).
- The overall aim of the HSS:
    - To provide benchmark data for assessing the safety of the existing ICCS HCI for later comparison with the UCMP HCI.
- The specific aim of the SIMEX:
    - The aim is not to assess the controller, it is to assess how good the ICCS HCI is at supporting operator situational awareness.
- Each SIMEX and debrief will take approximately 1.5 hour and will be structured as follows:
    - Personal Details
    - Simulation (1hr)
    - Post-SIMEX Debrief (30 min)

PERSONAL DETAILS

Name: Rank: Description of SIMEX:

Years in OS(FC) branch:

Age:

Gender:

Hours on duty:

Hours on console:

Brief Outline of UKADGE Experience & Training:

SIMULATION EXERCISE BRIEF

- The SIMEX will last approximately 1 hour.
- Fg Off Jim Bailey will act as the Simulation Coordinator (SC) and all ac coordination/operational queries should be directed to him during the SIMEX.
- The SIMEX will be frozen at random points and the controller will be asked to turn away from the console and answer a number of questions based on the sortie.
- The aim is not to assess the controller, it is to assess how good the ICCS HCI is at supporting operator situational awareness - **do not worry about your answers.**
- Your answers will not be revealed **to anyone**.
- Please do not discuss the SIMEX details or questions with other controllers - **it will invalidate all the data if people know what to expect**.

POST-SIMEX DEBRIEF

- The post-simulation debrief will last for a maximum of 30 mins.
- The controller will be asked a number of questions based on the incorrect answers given to the SIMEX questions:

SIMEX Validity

The SIMEX was a realistic FC sortie	disagree										agree
	0	1	2	3	4	5	6	7	8	9	
The SIMEX freezes did not interfere with my SA	disagree										agree
	0	1	2	3	4	5	6	7	8	9	
The probe questions were relevant to my SA	disagree										agree
	0	1	2	3	4	5	6	7	8	9	
The SIMEX freezes were not intrusive	disagree										agree
	0	1	2	3	4	5	6	7	8	9	

Situational Awareness Questions

- SIMEX questions answered incorrectly =
- For each incorrect answer ask:

Sample Situation

- *What information did you actively sample from the interface?*

- *What information was presented to you without actively looking for it?*

- *Was there any other information that could have helped you had it been available?*

<u>Modify Awareness</u>

- *What information lead you to modify your awareness?.*

- *What information did you decide was irrelevant?*

<u>Direct Consciousness</u>

- *How did your awareness at this point direct your subsequent action?*

- *How did your interaction with other people directly or indirectly involved in the sortie direct your subsequent actions?*

- *How did your previous training direct your subsequent actions?*

- The controller will be given an opportunity to ask any questions or add any extra information deemed relevant to the development of the UCMP HCI.

SAPAT HAZARDOUS INTERACTION LOG

The following table shows a log of all Interaction Hazards observed and analysed during the Pilot Study and the main UKADGE System Safety Study.

Interaction Breakdowns are characterised as those that occur when human-computer communication is interrupted for example, when a system behaves differently than was anticipated by the user. Interaction breakdowns can be explained in AT terms as a developmental change from Operation → Action

Automatic Interactions are characterised as those that normally require conscious actions but are achieved through automatic operation. In AT terms, these interactions are characterised as developmental changes from Action → Operation.

ISSAM Phase (Hazard No.)	Interaction Hazard Type	SA Process Breakdown	Interaction Description	SA Source/ICCS Interface Components	Associated Hazard(s) (From PHI Table 7.1)
Pilot Study P1	Breakdown (Operation → Action)	Direct situated action	Cancelling distracting alerts & alarms.	Situational Support Data/SFK, ITD,Qwerty Keyboard	No SA Data
*P2	Automatic (Action → Operation)	Modify awareness	Cancelling multiple alerts & alarms	Situational Support Data/SFK, ITD,Qwerty Keyboard	Erroneous SA Data
Video Analysis V1	Breakdown (Operation → Action)	Sample situation	Obtaining SA data from ITD - Emergency squawk.	Situational Support Data/SFK, ITD, Qwerty Keyboard	No SA Data
V2	Breakdown (Operation → Action)	Sample situation	Changing map range scales.	Situational Support Data/SFK	No SA Data
V3	Automatic (Action → Operation)	Modify awareness	Unintentionally clear all plot labels.	Situational Support Data/SFK	Erroneous SA Data
V4	Breakdown (Operation → Action)	Sample situation	Plot SIF	Situational Support Data/UC, SFK, Qwerty Keyboard, Rolling Ball	No SA Data

Simulation S1	Automatic (Action → Operation)	Modify awareness	Unintentionally deselect TPO comms during update when intending to mute incoming FA	Comms Subsystem/Comms Panel	No Feedback
S2	Breakdown (Operation → Action)	Direct situated action	Linking wrong missions	Situational Support Data/UC, TTD, SFK, Qwerty Keyboard & Ball	Erroneous SA Data
*S3	Automatic (Action → Operation)	Modify awareness	Cancelling multiple alerts & alarms	Situational Support Data/SFK, ITD,Qwerty Keyboard	Erroneous SA Data
S4	Breakdown (Operation → Action)	Sample Situation	Plot SIF Failure	Situational Support Data/UC, SFK, Qwerty Keyboard, Rolling Ball	No SA Data
S5	Breakdown (Operation → Action)	Direct Situated Action	De-select Comms	G/A Comms Data /UC, SFK, Comms Panel	No Comms
S6	Breakdown (Operation → Action)	Sample Situation	Use Comms Panel (PTT)	G/A Comms Data /UC, SFK, Comms Panel	No Comms
S7	Automatic (Action → Operation)	Direct Situated Action	Co-ordinate with a/c using incorrect callsign	G/A Comms Data /UC, SFK, Comms Panel	Erroneous Comms
S8	Automatic (Action → Operation)	Sample Situation	Verify wrong a/c 'Charlie' Height (looking at one ac talking to another)	Situational Support Data/SFK, Rolling Ball, Comms Panel (PTT)	Erroneous Comms
*S9	Automatic (Action → Operation)	Direct Situated Action	Log off EDDIE instead of closing window.	Situational Support Data/EDDIE, Mouse	No SA Data
S10	Breakdown (Operation → Action)	Sample Situation	Use Special Function Keys (SFKs) wrong sequence	Situational Support Data/UC, SFK.	No SA Data
S11	Breakdown (Operation →	Direct Situated Action	Input incorrect Regional Pressure Setting tote data via	Situational Support Data/UC, SFK, Qwerty	Erroneous SA Data

	Action)		Keyboard	Keyboard	
S12	Automatic (Action → Operation)	Modify Awareness	Flight Safety instruction from ac acknowledged not understood	G/A Comms Data /UC, SFK, Comms Panel	Erroneous SA Data
S13	Breakdown (Operation → Action)	Sample Situation	Listen to a/c while talking G/G - missed critical fuel state.	G/A Comms Data /UC, SFK, Comms Panel	No SA Data
S14	Breakdown (Operation → Action)	Direct Situated Action	Use wrong a/c callsign	G/A Comms Data /UC, SFK, Comms Panel	Erroneous Comms

Note 1: Due to the limitations of the simulation environment, no data was collected on the TACRO hazards identified during the Preliminary Hazard Analysis in section 7.2.

Note 2: Hazards marked with an asterix (*) are explicitly referred to in the text of this dissertation.

APPENDIX O - TANKING SAGAT SIMULATION DATA

RAW SAGAT SCORES

Subject	TA1	TA2	TA3	TA4	TA5	TA6	TB1	TB2	TB3	TB4	TB5	TB6	TC1	TC2	TC3	TC4	TC5	TC6
T1	1	1	1	1	1	0	1	0	0	0	0	1	0	0	0	1	1	0
T2	1	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	0
T3	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0
T4	1	1	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0
T5	1	1	0	1	1	0	0	1	0	0	0	0	1	1	1	1	0	0
T6	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0
T7	1	1	0	1	0	0	0	0	0	1	1	1	0	0	0	1	1	0

Subject	TA1	TA2	TA3	TA4	TA5	TA6	TB1	TB2	TB3	TB4	TB5	TB6	TC1	TC2	TC3	TC4	TC5	TC6
Total	5	7	1	4	5	0	1	1	2	3	3	5	2	1	2	6	3	0

Subject	TD2	TD3	TD4	TD5	TD6	TE1	TE2	TE3	TE4	TE5	TE6
T1	0	1	1	0	0	1	0	0	1	0	0
T2	0	1	0	0	0	1	1	0	1	1	1
T3	0	1	0	0	0	0	0	0	1	1	0
T4	0	1	1	1	0	0	0	0	0	0	0
T5	0	1	0	0	0	1	0	1	1	1	0
T6	1	1	0	0	0	0	0	1	0	1	1
T7	0	0	1	0	1	0	1	1	0	0	0

Subject	TD2	TD3	TD4	TD5	TD6	TE1	TE2	TE3	TE4	TE5	TE6
Total	1	6	3	1	1	3	2	3	4	4	2

SIMULATION SUBJECT BREAKDOWN

Subject	Rank	Trade	Age	M/F	Exp	Console Hrs	A1	A2	A3	A4	A5	A6	%	B1	B2	B3	B4	B5	B6	%	C1	C2	C3	C4	C5	C6	%
T1	Sgt		32	M	8	3	1	1	1	1	1	0	83.3%	1	0	0	0	0	1	33.3%	0	0	0	1	1	0	33.3%
T2	Flt Lt	WC	27	M	4	3	1	1	0	0	1	0	50.0%	0	0	1	0	1	1	50.0%	1	0	1	1	0	0	50.0%
T3	FS		38	M	7	2	0	1	0	1	1	0	50.0%	0	0	0	0	1	0	16.7%	0	0	0	1	0	0	16.7%
T4	WO		42	M	14	6	1	1	0	0	1	0	50.0%	0	0	1	1	0	1	50.0%	0	0	0	0	0	0	0.0%
T5	F/O	LCR	25	M	2	0	1	1	0	1	1	0	66.7%	0	1	0	0	0	0	16.7%	1	1	1	1	0	0	66.7%
T6	Flt Lt	SFC	28	M	6	0	0	1	0	0	0	0	16.7%	0	0	0	1	0	1	33.3%	0	0	0	1	1	0	33.3%
T7	Lt	RN FA	26	M	5	1.5	1	1	0	1	0	0	50.0%	0	0	0	1	1	1	50.0%	0	0	0	1	1	0	33.3%

Subject	D1	D2	D3	D4	D5	D6	%	E1	E2	E3	E4	E5	E6	%	Overall
T1	1	0	1	1	0	0	50.0%	1	0	0	1	0	0	33.3%	46.7%
T2	0	0	1	0	0	0	16.7%	1	1	0	1	1	1	83.3%	50.0%
T3	0	0	1	0	0	0	16.7%	0	0	0	1	1	0	33.3%	26.7%
T4	0	0	1	1	1	0	50.0%	0	0	0	0	0	0	0.0%	30.0%
T5	0	0	1	0	0	0	16.7%	1	0	1	1	1	0	66.7%	46.7%
T6	1	1	1	0	0	0	50.0%	0	0	1	0	1	1	50.0%	36.7%
T7	0	0	0	1	0	1	33.3%	0	1	1	0	0	0	33.3%	40.0%

APPENDIX P - 2V2 SAGAT SIMULATION DATA

RAW SAGAT SCORES

Subject	VA1	VA2	VA3	VA4	VA5	VA6	VB1	VB2	VB3	VB4	VB5	VB6	VC1	VC2	VC3	VC4	VC5	VC6
V1	0	1	1	0	1	1	1	0	1	0	0	1	1	0	0	1	1	1
V2	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
V3	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	1	0	1
V4	1	1	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0
V5	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	1	1	1
V6	1	1	0	0	1	0	1	0	1	1	0	0	1	1	0	1	0	1
V7	0	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1	0	1

Subject	VA1	VA2	VA3	VA4	VA5	VA6	VB1	VB2	VB3	VB4	VB5	VB6	VC1	VC2	VC3	VC4	VC5	VC6
Total	2	5	3	2	5	2	2	0	4	3	0	4	3	2	1	6	2	5

Subject	VD1	VD2	VD3	VD4	VD5	VD6	VE1	VE2	VE3	VE4	VE5	VE6
V1	0	0	0	1	0	1	0	1	0	1	1	0
V2	0	1	1	1	0	1	0	0	0	1	0	0
V3	0	0	0	0	0	1	1	0	1	1	0	0
V4	1	0	0	0	0	1	0	0	1	1	1	1
V5	0	0	0	1	0	1	0	0	0	1	0	0
V6	1	0	0	1	1	1	1	1	1	0	1	1
V7	1	0	0	0	0	1	0	0	1	0	1	0

Subject	VD1	VD2	VD3	VD4	VD5	VD6	VE1	VE2	VE3	VE4	VE5	VE6
Total	3	1	1	4	1	7	2	2	4	5	4	2

SIMULATION SUBJECT BREAKDOWN

Subject	Rank	Trade	Age	M/F	Exp	Console Hrs	A1	A2	A3	A4	A5	A6	%	B1	B2	B3	B4	B5	B6	%	C1	C2	C3	C4	C5	C6	%
V1	F/O	?	25	M	2		0	1	1	0	1	1	66.7%	1	0	1	0	0	1	50.0%	1	0	0	1	1	1	66.7%
V2	FS		38	M	7	1	0	1	0	0	0	0	16.7%	0	0	1	0	0	0	16.7%	0	0	0	0	0	0	0.0%
V3	Flt Lt		28	M	6		0	0	1	0	1	0	33.3%	0	0	0	1	0	1	33.3%	0	0	0	1	0	1	33.3%
V4	Flt Lt	1ACC	29	M	6	1	1	1	0	1	1	0	66.7%	0	0	0	0	0	1	16.7%	1	0	0	1	0	0	33.3%
V5	Flt Lt	CR WC	29	M	4	0	0	0	0	1	0	0	16.7%	0	0	1	0	0	0	16.7%	0	1	1	1	1	1	83.3%
V6	Lt		26	M	5		1	1	0	0	1	0	50.0%	1	0	1	1	0	0	50.0%	1	1	0	1	0	1	66.7%
V7	Flt Lt	CR WC	30	M	7	0	0	1	1	0	1	1	66.7%	0	0	0	1	0	1	33.3%	0	0	0	1	0	1	33.3%

Subject	D1	D2	D3	D4	D5	D6	%	E1	E2	E3	E4	E5	E6	%	Overall
V1	0	0	0	1	0	1	33.3%	0	1	0	1	1	0	50.0%	53.3%
V2	0	1	1	1	0	1	66.7%	0	0	0	1	0	0	16.7%	23.3%
V3	0	0	0	0	0	1	16.7%	1	0	1	1	0	0	50.0%	33.3%
V4	1	0	0	0	0	1	33.3%	0	0	1	1	1	1	66.7%	43.3%
V5	0	0	0	1	0	1	33.3%	0	0	0	1	0	0	16.7%	33.3%
V6	1	0	0	1	1	1	66.7%	1	1	1	0	1	1	83.3%	63.3%
V7	1	0	0	0	0	1	33.3%	0	0	1	0	1	0	33.3%	40.0%

APPENDIX Q - COFFEE 'C' SAGAT SIMULATION DATA

RAW SAGAT SCORES

Subject	CA1	CA2	CA3	CA4	CA5	CA6	CB1	CB2	CB3	CB4	CB5	CB6	CC1	CC2	CC3	CC4	CC5	CC6
C1	0	0	0	0	0	1	1	0	0	0	1	0	1	1	1	1	1	1
C2	0	0	1	0	0	1	0	1	0	0	0	0	0	1	1	1	1	1
C3	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1
C4	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1
C5	1	0	0	0	0	1	1	1	0	0	1	0	0	0	1	1	1	1
C6	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	1
C7	0	1	1	0	0	0	1	1	0	1	1	0	1	1	1	1	1	1

Question	CA1	CA2	CA3	CA4	CA5	CA6	CB1	CB2	CB3	CB4	CB5	CB6	CC1	CC2	CC3	CC4	CC5	CC6
Total	1	1	2	0	0	4	5	4	0	1	3	0	3	5	7	4	5	7

Subject	CD1	CD2	CD3	CD4	CD5	CD6	CE1	CE2	CE3	CE4	CE5	CE6
C1	0	0	0	0	1	1	0	0	1	1	1	1
C2	0	0	0	0	0	0	1	0	0	0	1	1
C3	0	0	0	1	1	0	1	0	1	0	1	0
C4	0	0	0	0	1	0	0	0	0	1	1	0
C5	1	0	1	0	0	1	1	0	1	0	1	1
C6	1	0	0	1	1	0	0	0	1	1	1	1
C7	1	1	0	0	0	0	1	1	0	1	1	0

Question	CD1	CD2	CD3	CD4	CD5	CD6	CE1	CE2	CE3	CE4	CE5	CE6
Total	3	1	1	2	4	2	4	1	4	4	7	4

SIMULATION SUBJECT BREAKDOWN

Subject	Rank	Trade	Age	M/F	Exp	Console Hrs	A1	A2	A3	A4	A5	A6	%	B1	B2	B3	B4	B5	B6	%	C1	C2	C3	C4	C5	C6	%
C1	Flt Lt	CR WC	27	M	3.5	0	0	0	0	0	0	1	16.7%	1	0	0	0	1	0	33.3%	1	1	1	1	1	1	100.0%
C2	Sqn Ldr	MC CR	40	M	15		0	0	1	0	0	1	33.3%	0	1	0	0	0	0	16.7%	0	1	1	1	1	1	83.3%
C3	FS		38	F	7.5	0	0	0	0	0	0	1	16.7%	1	0	0	0	0	0	16.7%	0	0	1	0	1	1	50.0%
C4	Flt Lt	WC/FC	32	M	10	0	0	0	0	0	0	0	0.0%	0	1	0	0	0	0	16.7%	0	1	1	0	0	1	50.0%
C5	F/O	SFC	24	M	4.5	0	1	0	0	0	0	1	33.3%	1	1	0	0	1	0	50.0%	0	0	1	1	1	1	66.7%
C6	Flt Lt	MC/FA	38	M	17	0	0	0	0	0	0	0	0.0%	1	0	0	0	0	0	16.7%	1	1	1	0	0	1	66.7%
C7	F/O	SFC	25	M	3.5	0	0	1	1	0	0	0	33.3%	1	1	0	1	1	0	66.7%	1	1	1	1	1	1	100.0%

Subject	D1	D2	D3	D4	D5	D6	%	E1	E2	E3	E4	E5	E6	%	Overall
C1	0	0	0	0	1	1	33.3%	0	0	1	1	1	1	66.7%	50.0%
C2	0	0	0	0	0	0	0.0%	1	0	0	0	1	1	50.0%	36.7%
C3	0	0	0	1	1	0	33.3%	1	0	1	0	1	0	50.0%	33.3%
C4	0	0	0	0	1	0	16.7%	0	0	0	1	1	0	33.3%	23.3%
C5	1	0	1	0	0	1	50.0%	1	0	1	0	1	1	66.7%	53.3%
C6	1	0	0	1	1	0	50.0%	0	0	1	1	1	1	66.7%	40.0%
C7	1	1	0	0	0	0	33.3%	1	1	0	1	1	0	66.7%	60.0%

APPENDIX R - GENERAL SAGAT SIMULATION DATA

SUBJECTS RANKED BY EXPERIENCE

Subject	Rank	Age	Gender	Experience (Years)	Console Time	A	B	C	D	E	Overall
T5	F/O	25	Male	2	0	66.7%	16.7%	66.7%	16.7%	66.7%	46.7%
V1	F/O	25	Male	2		66.7%	50.0%	66.7%	33.3%	50.0%	53.3%
C7	F/O	25	Male	3.5	0	33.3%	66.6%	100.0%	33.3%	66.6%	60.0%
C1	Flt Lt	27	Male	3.5	0	16.7%	33.3%	100.0%	33.3%	66.6%	50.0%
T2	Flt Lt	27	Male	4	3	50.0%	50.0%	50.0%	16.7%	83.3%	50.0%
V5	Flt Lt	29	Male	4	0	16.7%	16.7%	83.3%	33.3%	16.7%	33.3%
C5	F/O	24	Male	4.5	0	33.3%	50.0%	66.7%	50.0%	66.7%	53.3%
T7	Lt	26	Male	5	1.5	50.0%	50.0%	33.3%	33.3%	33.3%	40.0%
V6	Lt	26	Male	5		50.0%	50.0%	66.7%	66.7%	83.3%	63.3%
V3	Flt Lt	28	Male	6		33.3%	33.3%	33.3%	16.7%	50.0%	33.3%
T6	Flt Lt	28	Male	6	0	16.7%	33.3%	33.3%	50.0%	50.0%	36.7%
V4	Flt Lt	29	Male	6	1	66.7%	16.7%	33.3%	33.3%	66.7%	43.3%
V7	Flt Lt	30	Male	7	0	66.7%	33.3%	33.3%	33.3%	33.3%	40.0%
V2	FS	38	Male	7	1	16.7%	16.7%	0.0%	66.7%	16.7%	23.4%
T3	FS	38	Male	7	2	50.0%	16.7%	16.7%	16.7%	33.3%	26.7%
C3	FS	38	Female	7.5	0	16.7%	16.7%	50.0%	33.3%	50.0%	33.3%
T1	Sgt	32	Male	8	3	83.3%	33.3%	33.3%	50.0%	33.3%	46.7%
C4	Flt Lt	32	Male	10	0	0.0%	16.7%	50.0%	16.7%	33.3%	23.3%
T4	WO	42	Male	14	6	50.0%	50.0%	0.0%	50.0%	0.0%	30.0%
C2	Sqn Ldr	40	Male	15		33.3%	16.7%	83.3%	0.0%	50.0%	36.7%
C6	Flt Lt	38	Male	17	0	0.0%	16.7%	66.7%	50.0%	66.7%	40.0%