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Team Error in Air Traffic Control:

recognition, detection and recovery.

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A thesis submitted for the degree of
Master of Ergonomics
at Massey University
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New Zealand

June 2002

Acknowledgements

No work of this nature is a solo effort. There are many people who have been willing to share their ideas and time in order for these studies to be a success. Firstly my discussions and continued debate with Steve Shorrock, Mike O'Leary, James Reason and Rene Amalberti have been excellent in the development of my thinking. However without the support and encouragement of the air traffic controllers this work would never have been possible. For this I would like to thank my ATC friends in Australia and New Zealand, the controllers from Dutch Mil., Greg Hindson and all those who were such a vital technical support in the simulation studies.

I would also like to acknowledge the help given by the members of the Safety Group at ATC, the Netherlands, who when heavily involved in their own incident investigations were always happy to help me out in my work.

Thanks also to Pink, Emily and Floyd who after waiting so patiently may now be able to have some attention. However the biggest thanks goes to my husband, who gave me the space and support to pursue this work, the encouragement that I was doing something valuable but more importantly, as a controller, was my greatest critic.

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ABSTRACT

'Accidents appear to be the result of highly complex coincidences which could rarely be foreseen by those involved ... accidents do not occur because people gamble and lose, they occur because people do not believe that the accident that is about to occur, is at all possible.'

Wagenaar and Groeneweg (1987)

The air traffic management system is considered a high reliability, low risk activity. It is also seen as inherently safe despite the tightly coupled nature of the activities involved. Tightly coupled systems are characterised by time-dependant processes in which planned and unplanned interactions occur quickly and are also associated with the co-ordination of activities which must occur in a pre-defined sequence adhering to a set of strict rules and procedures. They are also very precise and vulnerable to unexpected events in which the activities must be undertaken correctly or not at all. All these characteristics can be found in the air traffic management (ATM) system and in particular in their 'team related' activities. In these systems there is little opportunity to improvise when things go wrong, and recovery is very time dependant.

However there is almost no existing information about the types of error found in the ATM system and the recognition, detection and recovery from the errors made. Therefore in order to obtain information to better understand these issues, three distinct but complimentary studies were undertaken.

In the first study a technique to identify both the cognitive and contextual factors of erroneous behaviour was developed. Several incidents were analysed using this technique, revealing that planning and decision making was the most problematic cognitive area and team difficulties accounted for the majority of the contextual conditions associated with the errors.

Results also indicated the importance of the relationship of all the members of the air traffic management team – including pilots – and their role in the detection, recovery and management of the situation. This resulted in the development of a new technique – *the Joint Error Detection of Incidents – JEDI* – to be used in the exploration of the chronology of occurrences.

In the second study controllers were questioned with regard to their attitudes towards error, safety and teamwork. Findings from this work suggested the majority of controllers were

aware of the team interaction issues, but were more concerned with their relationship with other teams, particularly in emergencies and unusual situations.

In the third, a study was undertaken to record the erroneous activities and outstanding events during ATM simulation sessions. The results of these activities revealed that rather than controllers making errors, they were able, in the majority of the cases, to assess the outstanding event in relation to their professional knowledge and experience. These events have been termed *'Expert Judgement Deviations'* and consist of behaviour which enable the system to continue in its tightly coupled structure. This study was also able to determine the differences between errors and violations and again indicated that errors were mostly attributable to failures in planning and decision making. This study also highlighted the importance of team issues but demonstrated that the team, as defined in the literature, was probably not a suitable concept in such an environment. From the insights gained in this research it was argued that, although the team was an important concept, the separation of aircraft undertaken by controllers was an individual activity. However it was also realised that without the co-operation and co-ordination between controllers the overall goals of safety would be compromised. Therefore the term *'dynamic sets'* was introduced and used to describe the majority of the controllers work in the Air Traffic Management system.

PREFACE

The initial focus for this work evolved from two major European air traffic management projects under the auspices of the Eurocontrol EATCHIP and EATMP programmes. Within these projects I was the technical manager and leading research scientist. However despite their ground breaking work within the air traffic management system; Team Resource Management is now used throughout Europe, in Australia and Japan and the Human Error in ATM retrospective approach is used throughout Europe and the United States of America, there has been no effort to include the team and group dynamics within human error recognition, detection and recovery. It is for this reason that these issues are now tackled within this thesis. Initially the issues with regard to the present and future air traffic management system are discussed and the problems of changing systems, including new technology and procedures, are explored. This leads to the observation that the 'team' within this environment has never had a more important role in terms of the errors which are generated, and more importantly those errors which are recognised and managed. A detailed exploration of the team and the role it plays within the air traffic control environment reveals

there exists a well developed ability to deviate from accepted practice and that the team is capable of not only exacerbating critical events but also recovering from these potential threats to safety.

As a result of the earlier phases of this work the following articles have been either published or accepted for publication. The first two papers relate to the early developments regarding the human error identification within air traffic management incident analysis. The third refers to the work undertaken in the analyses of air traffic incidents and the last is associated with the work undertaken in the simulated air traffic control environment.

- Isaac, A.R., Shorrock, S.T. and Kirwan, B. (2002) Human Error in European Air Traffic Management: the HERA project. Reliability Engineering and Safety Science 75 (2) : 257-272
- Pounds, J and Isaac, A.R. (2002) Development of an FAA-EUROCONTROL approach to the analysis of human error in ATM. Report N0. DOT/FAA/AM/02 (in press).
- Isaac, A.R. (2002) Protecting the ATM system from human error: the JANUS approach. Proceedings of the fifth AAPs symposium. Ashgate:Aldershot (in press).
- Isaac. A.R. (2002) Human Error in Air Traffic Mangement: deviation or deviance? In P.T. McCabe (Ed) Contemporary Ergonomics 2002 (in press).

CHAPTER 1. INTRODUCTION

1.1 The air traffic control environment

At around 10:30 hours on June 30th 1956, United Airlines Flight 718, a DC7 Mainliner collided with Trans World Airlines Flight 2, a Lockheed Constellation, over the Grand Canyon, USA. This catastrophe effectively launched the transformation of air traffic control into the system that it has become today.

The underlying goal of air traffic control is to separate air traffic in a safe, expeditious and orderly, manner; although such terms as efficiency and capacity increases have recently been added to the controlling objectives. In terms of the activities of the controllers, there is much in common with general control of goal-directed behaviours. The main difference between air traffic control and the cognitive control of one's own actions, is that the controller has to direct external activity which has to be co-ordinated with others. However in simple terms there are four main activities which can describe the tasks of the controller; checking, diagnosing, controlling and monitoring.

Checking is a process of situational scanning, which takes place intermittently or as a consequence of unexpected events. Diagnosing is an active process of information search, which tries to explain unexpected or new traffic situations. Controlling in its general sense denotes an intervention, which attempts to change the traffic situation if necessary. Monitoring refers to the continuous or intermittent comparison between the anticipated traffic situation and the actual system state. As long as the traffic situation develops as anticipated and planned, the controller either has to monitor the situation or execute control actions. As long as the situational conditions remain normal, and the control actions result in the expected changes, the mental picture created by the controller of the traffic will correspond to their mental model or reality.

From time to time the controller has to reaffirm that the situational conditions really are as expected by checking the whole situation, including the less attended areas. A comparatively low rate of checking activity in comparison to monitoring activity will be observed in well controlled situations. In the case of unexpected events, new traffic or a mismatch between the planned and observed situation, the mode of action changes from monitoring and

controlling to checking and diagnosing. Control is no longer conducted in an anticipatory proactive way, but in a more situationaly-determined reactive way. The cause of unexpected events has to be inferred from the mental model or the knowledge base of the controller. Where there is no obvious explanation, further checks have to be conducted to re-establish an adequate picture of the situation. It is the breakdown of these activities that cause the error prone situations in air traffic control.

Although controllers will tend to train for a number of different functional environments (tower, approach and en-route etc), they will often remain in one or other of these positions for a considerable length of time. Indeed it is often said that a controller is not fully functional for approximately 3 years, depending on the traffic density and complexity. However within each of the functional areas there are various differences in terms of the cognitive activities that are demanded. It is appropriate to detail these differences to enable any specific findings, which may be found as a result of this research to be adequately discussed. The following table represents the functional differences of controllers in the 4 main controlling positions – Tower, Approach, En-route and Oceanic.

Table 1.1 : Functional positions and their cognitive activities in air traffic control

Tower Control[1] (non radar)	**Approach Control (radar)**	**En-route Control (radar)**	**Oceanic Control (non radar)**
Direct view of the traffic situation	Symbolic representation of the traffic situation	Symbolic representation of the traffic situation	No direct representation of the traffic situation
High memory demand	Moderate memory demand	Moderate memory demand	High memory demand
Visual estimation	High demand for mental projection	Moderate demand for mental projection	High demand for mental projection
High tactical planning	High tactical planning	Combination of strategic and tactical planning	High strategic planning
Few delays in ground communication	Few delays in ground communication	Normally no delay in air-ground communications	Often long delays in air-ground communications
Rapid event development	Quick event development	Moderately quick event development	Slow event development

[1] It should be noted that there are two positions in the tower which have specific duties. These are the ground controller and the tower controller.

As well as the individual activities which are indicated in the above table it is obvious that controllers working in these positions also have to interact with their colleagues. These relationships will become more important as technology increases and devolves more decision making to computers.

1.2 Human error in the air traffic management system

Human error is a major contributor to Air Traffic Control (ATC) incidents, with some reviewers suggesting that the human error contribution is in the order of 90% or more (Kinney, Spahn and Amato, 1977; FAA, 1990). A recent survey of European ATM systems indicated that of those accidents and incidents which were attributable to the ATM system, 75%, were due to human error, 21% to procedure problems and 4% to equipment failures (Eurocontrol, 2002). However it should be stated that most comparable industries have similar human error contributions in incidents e.g. nuclear power and medicine - 70-90% (Reason, 1998).

Controllers often handle high numbers of aircraft movements every day without major incident and so the ATM system is in fact very reliable. However, the fact remains that almost all incidents do involve human error. Hence, if such errors could be reduced, or the system could be made more tolerant, then there would be large increases in safety, with the additional potential for significant ATM capacity gains.

One potential engineering solution to the problem of human error in this domain is that of automation. However, paradoxically automation can often increase the importance and impact of human error (Bainbridge, 1987; Reason, 1998). This problem has been seen in aviation via the so-called 'glass cockpit' generation of aircraft (Wiener, 1988; Billings, 1997). This is because automation merely shifts the location of human error from the 'operator' to the designer, maintenance personnel, and the supervisor who must deal with automation problems and failures. Furthermore, in ATM, full automation is not foreseen as a feasible option for some decades to come, because human traits such as flexibility and adaptability, problem solving and decision-making capabilities are needed to optimise dynamic ATM situations. Therefore, automation, or rather computerised support, could help ATM to cope with human error, but it alone will not prevent human error occurrences.

1.3 The need for the present approach

Air Traffic Management (ATM) is currently under pressure, as traffic levels increase. Airspace in many parts of the world is already complex and congested, and there is also pressure from the airlines, who are under strong competitive commercial constraints, to optimise routes and timings. These issues lead to complexity and time pressure in ATM operations that can subsequently lead to errors. Additionally, many ATM systems are currently being upgraded and developed into 'next generation' systems, which include computerised displays with new functionality, and computerised tools. There is also the prospect in the near future of the introduction of datalink technology, which will significantly impact the method of operation in ATM.

These major shifts in work practices will affect both controller and pilot performance, and new opportunities for error could arise, particularly in the 'transition period' during which new systems and practices are introduced. These developments suggest that the ATM system is at the beginning of a long period of significant change and evolution, a period that will possibly see increased error rates, and potentially new errors. This points to the need for the development of an approach to better understand errors, and particularly those made in a team situation, which will be undertaken in the following way.

Firstly, it is hoped that the new models, techniques and insights developed in this research will be seen as adding value to existing approaches. As noted above, concern regarding human error has not been the most important concern in ATM (although it has always been a major concern), and so many approaches will have evolved over time, adding new categories of error to existing systems as each new error arises. What this research will attempt to do is define all error types that can occur or could occur, whether with existing or future systems. The research will do this by using more general human error approaches based on research in other industries. It will also try to identify the team error dynamics in the ATM system which has not been tackled before.

The approach being developed in this research will attempt to carry out a 'deeper' analysis, in the psychological sense, than previous and existing error analysis systems. Other industries have realised the need to take this approach, for two fundamental reasons. The first is that such depth of analysis prevents ambiguities and aggregation of errors that are

fundamentally different. The second reason is that error prevention and reduction measures are never easy to achieve. The more precise the understanding of the causes, the more successful error prevention and reduction measures are likely to be.

1.4 The significance of the research

The purpose of this work is to increase the effectiveness of error identification and prevention, particularly in the application of team error. This work has arisen as a result of the increasing importance of human error, error detection and error recovery in ATM. In particular, the analysis of human error in ATM is becoming more important as traffic levels increase, as airspace becomes more harmonised, and as ATM operational centres make more use of computerised support and automation. Human error is a potential weak link in the ATM system and, therefore, measures must be taken to minimise errors and their impact, and to maximise other human abilities such as error detection and recovery.

The aim of this research is therefore to increase knowledge and understanding of human performance mechanisms and the human errors with which they are associated. While investigation of incidents within the ATM environment often conclude human error as the main causal factors, investigation of the human performance factors aims to go beyond this category alone, analysing the different facets of the situation and trying to understand the mechanisms and context which led to the error, particularly the team contribution.

1.5 Hypotheses

Based on the theoretical frameworks developed in chapters 2, 3 and 4 of this thesis, the following hypotheses are proposed:

1. The majority of ATC incidents involve problems of judgement and decision making.
2. The majority of ATC incidents involve the ATC 'team` - which includes both the controllers and pilots.
3. The highest percentage of errors found in ATC operations comprise communication and co-ordination failures.
4. The successful recovery from error(s) in the ATC environment can be identified within Rasmussen's `mistakes` categorisation.

CHAPTER 2. HUMAN ERROR

2.1 Review of human error

Research studies on human error are not new, however many concepts have been extensively reviewed during the last century. The earliest attempts to discuss the theoretical generation of error came from James (1890), and that of error classification by Sully (1881). This work led to more clinical approaches which explored the area of slips, (Fraud, 1914) which has become a recognised classification of an error. The clinical case study methodologies gave way to experimental laboratory methods when Head (1920) developed the schema concept to explain systematic errors that were apparent in memory tasks. Bartlett (1932) later applied this concept to the study of error in memory, thought and skilled performance.

In psychophysics and behavioural psychology scientists perceived error as the way to assess and measure the performance of experimental subjects; any deviation from an expected answer was considered as an incorrect perception and therefore an error (Green and Swets, 1966). Since the beginning of the last century, another area of research has been shown to be useful in human error research. Gestaltists, the theoreticians of the good form, discussed errors as part of data reorganisation, which provides access to the solution. They reported that the system of generic solutions for situations of errors and failures were memorised by subjects – try not to do that – rather than by the memory of the successful course. This thinking considered human error as having a beneficial and organisational role in cognition.

A similar logic was behind the work on action control by Dorner (1990) who carried out experiments with 'microworlds'[2]. He found that the reasons for failure were stereotyped; individuals running into difficulties tend to escape into tried and tested solutions leaving out difficult things. In these examples individuals carry out linear extrapolations and never take into account the collateral effect of the measures chosen. He also reported from his work that individuals tend never to learn from their failures and therefore fail to enhance their meta-knowledge.

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[2] Microworlds are simplified computer simulations of human complex activities at work e.g. fire-fighting, air traffic control or medical care.

However the study of human error never managed to achieve high priority in psychology before the end of the 1970s. With the occurrence of the first major modern industrial disasters caused by human error – Tenerife air crash, 1977 and the Three Mile Island nuclear explosion, 1979 – the subject became one of the most important industrial research areas. The human error reduction concept and its obvious link with human reliability was extensively explored in the next twenty years (Swain and Guttman,1983; Kirwan and Ainsworth, 1992 and Hollnagel, 1993).

Research was also funded in psychology which greatly increased psychological and psycho-sociological knowledge on the occurrence, type and mechanisms of human errors. The first influential books and papers on human errors (Norman 1981, Reason 1987) which discussed the distinction between routine errors (slips and lapses) and mistakes have become the oldest and most robust experimental work in this field. Research continued in the 1990's and progressively focused on the role of errors in accidents (Reason 1990). New concepts such as organisational safety emerged from these approaches, as well as a new modelling of the ecological role of error in cognition. The most significant results of this decade are described below.

1. Mistakes are cognitively useful and assist learning. Errors are therefore reported to be more frequent with beginners and decrease with experience, mainly because learning allows the development of automated behaviour. However this change to automated behaviour also changes the nature of errors (Rasmussen, 1983; Norman and Shallice, 1986). This can be illustrated in the following figure.

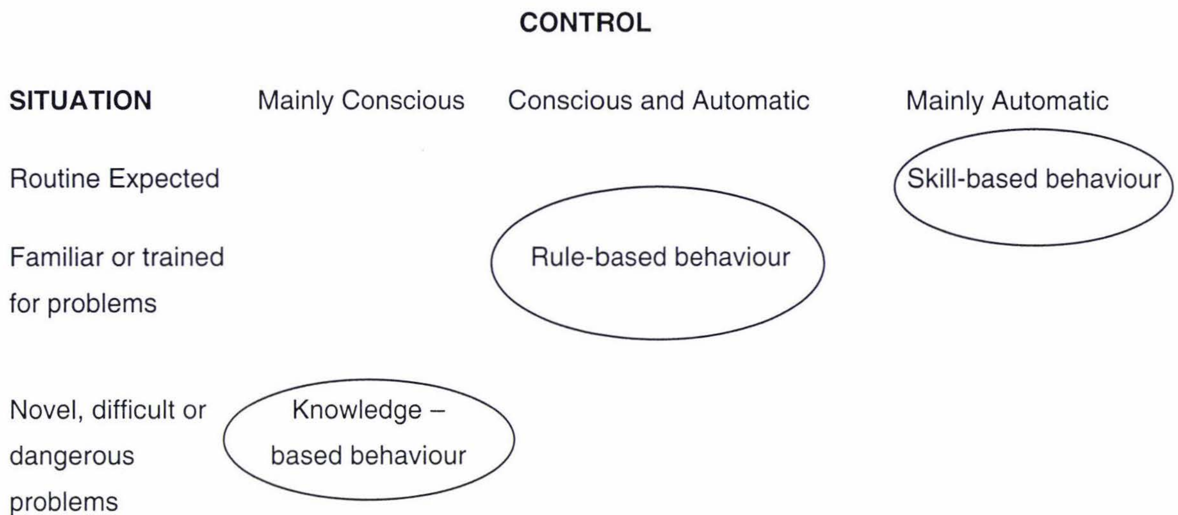


Figure 2.1 Situation – Control matrix

It is also recognised that erroneous behaviour consists of the opportunity to detect and recover errors and that if expertise is linked with these skills then their performance is more important than the production of errors themselves.

2. Mistakes made by individuals should be considered within a more systemic or sociological framework to enable the investigation of how these errors contribute to overall safety. Therefore in order to explain mistakes and the risk they place on the system, it is necessary to consider the entire contribution of individuals to systems operations. This change of focus considered two different but related issues. The first issue considered those active errors made by the front line operators who also had the ability to act as a defence when able to recognise, detect and recover these errors. The second issue was associated with 'latent' failures within the system which were not visable. These were usually generated by design and organisation, and in the end the overall system safety was the result of all in-depth defences (Reason, 1990; Maurino, Reason, Johnston and Lee, 1995).

3. Mistakes made by individuals are the consequences of the movement of socio-technical systems towards more complex structures. As a result the serious failures of these large technical systems do not result from a single error or breakdown, but a series of minor breakdowns and errors which could be considered normal in the context of increased pressure on production. Systems

which operate in such a way reveal that deviance becomes a standard of normal operators which reduces the opportunity for recovery from minor failures and therefore results in the possibility of a catastrophic accident or loss of control (Perrow, 1984; Vaughan,1996; Rasmussen, 1990).

4. Finally as a result of this previous work it was realised that errors are a product of cognitive activity, regulated within the context of cognitive performance control. That is, an operator does not regulate the risk of error, but regulates a high performance objective against the lowest execution cost. To the human, error is a necessary component of optimal performance and research is now focussed on the study of the cognitive mechanisms responsible in risk management.

In this respect recent studies have focussed on the role of error as a situational control variable which is associated with the control of dynamic cognition and illustrates the nature and role of error and its recovery (Plat and Amalberti, 2000).

These issues will be important in the present research and particularly as they relate to the air traffic management team environment.

2.2 Human error in air traffic management

There are few comprehensive studies reporting the details of human error within the air traffic management system. There are two main reasons for this situation. Firstly the task of identifying errors and their causes are often sponsored or requested by organisations who are interested in one small but significant area of detail within the larger system (FAA, Rogers and Nye,1993; Airservices Australia, Isaac,1995). This leads to a narrow focus on one particular issue within the ATM environment, such as communication or co-ordination. Secondly, and perhaps more importantly for this research, the source of error details, whether in a research project or incident/accident analysis report, are fraught with the problem of investigator bias and the various methodologies used to classify errors that are not standardised (Rasmussen,1983; Hawkins, 1987; Reason, 1987; Endsley. 1995).

A summary of those known studies regarding human error in air traffic management are detailed below.

Table 2.1: Summary of human error studies in ATM

Research Reference	Error Type/Classification	Findings
Allnut, 1976	Workload and errors	• Most errors occurred during light workload
Kinney, Spahn and Amato, 1977	Workload issues	• 70-74% of errors occur in light to moderate traffic complexity • 45% of errors occur in the first 15 minutes on position • 62% of errors occur when controllers have less than 6 months experience
Danaher, 1980	Errors in the ATC system	• 90% of all system errors occur from human mistakes in attention, judgement and communications
Langan-Fox and Empson, 1985	Observation of operation errors	• Error rates increased with workload ($F(2,14) = 5.36, p<0.01$) • Planning errors were more numerous than memory errors ($F(2, 14) = 5.74, p<0.05$)
Stager and Hameluck, 1990	Sector dynamics and error	• 26% of incidents occur when the radar and planner positions were combined
Redding, 1992	Situational Awareness and related activities	• The largest number of errors were when 8 aircraft or less were under control • 38% of errors were associated with misidentification or misuse of radar data • Communication and co-ordination problems accounted for over 60% of errors

Research Reference	Error Type/Classification	Findings
Schroeder and Nye, 1993	Workload issues	• Operational errors mostly occurred under average or low traffic complexity conditions
Rodgers and Nye, 1993	Workload and associated factors	• Most errors occurred when one aircraft was in level flight and the second aircraft was descending or ascending • Most severe errors occurred when 2 conflicting aircraft were in level flight at 29,000 feet or below • Horizontal separation was associated with more errors than vertical separation • Errors seem to be correlated (r=.74) with the following – control adjustments of merging and spacing traffic, climbing and descending flight paths, aircraft type mix, frequent co-ordination-heavy traffic
Isaac, 1995	Communication and co-ordination errors	• 40% of en-route errors were concerned with co-ordination failure • 43% of en-route errors were caused within communication
Cardosi and Murphy, 1995	Communication errors	• 31% of errors were concerned with incorrect altitude readback • 24% of errors were concerned with incorrect radio frequency changes • 10% of errors were concerned with the wrong aircraft which was identified • 6% of errors were concerned with

Research Reference	Error Type/Classification	Findings
		navigational routes • 7.5% of errors were associated with incorrect restrictions
Jones, 1996	Group dynamics and errors[3]	• More errors occurred when controllers failed to use constructive task management behaviour and information exchange
Rodgers, Mogford and Mogford, 1997	Airspace sector and associated factors	• Errors increased in high complexity traffic ($F_{2,42} = 5.45$, $p<.008$) • Errors increased with radio frequency congestion ($F_{2,42} = 6.20$, $p<.004$)
Mavor, McGee and Wickins 1997	Errors found in incidents	• Most incidents concern the following errors – forgetting to transfer information – non compliance with procedures – lack of concentration in low workload – incorrect phraseology
Durso, Truitt, Hackworth, Crutchfield and Manning, 1998	Situational Awareness	• Unaware (low SA) controllers made more perceptual and memory mistakes (X_2 (1, N=268) = 4.18, $p<.05$) • Aware (high SA) controllers committed more thinking mistake (X_2 (1, N=268)= 9.26, $p<.05$)
Weikert and Johansson, 1999	Errors found in incidents	• Most incidents were concerned with the following – handover on position – lack of concentration – lack of methodology

[3] Jones classified these as mishaps in the research

As can be seen from the review above there are many different studies which focus on different, albeit, overlapping activities. Often these studies fail to detail the population of controllers studied and their functional activities. Finally few studies discuss the type of error methodology or model on which they base their results. However it would seem from this research review that there are certain types of activities which seen to be error prone. These include:

- Communications between both pilot and ATC colleagues in adjacent sectors or centres
- Co-ordination between adjacent sectors
- Light workload in terms of the number of aircraft and their flight profile complexity
- High complexity including horizontal separation problems
- Controllers who were unaware or who reported low situation awareness

It is interesting to note that no research to date has specifically focussed on ATC team error, although Jones (1996) discusses the role of group dynamics in an error tolerant system.

However before these issues are discussed it is necessary to review the work in error modelling to establish a basis on which to analyse error in the air traffic management system, in particular how it is manifest in the dynamics of the team.

CHAPTER 3. THEORETICAL FRAMEWORKS

3.1 Human error modelling

Given the desirability of a methodology for analysing human errors, it is useful to research the methodologies that already exist. Currently, there are no 'off-the-shelf' ATM-oriented Human Error Analysis methodologies. This is partly because ATM has been a relatively high reliability organisation - human reliability and system reliability is higher than many other industries. There has therefore been little demand for such approaches, which could mean that ATM is somewhat 'naive' compared to other 'high risk' industries (e.g. nuclear power, chemical process and offshore petro-chemical industries). These other industries have developed approaches following large-scale catastrophes and accidents such as the Three-Mile Island and Chernobyl nuclear accidents, the Bhopal poisonous gas release, the Challenger explosion and the Piper Alpha oil platform fire. ATM can therefore borrow from other industry knowledge and experience and from general psychological understanding that has evolved over the past three decades concerned with industrially-related research in this area.

The nuclear power accident at Three-Mile Island raised the important influence of human error in many industries. Within a few years of this accident the emerging approach of Human Reliability Assessment (HRA) became mandatory in all nuclear power risk assessments worldwide. HRA aims to identify and predict human errors in complex systems. During the eighties in particular there was further development of HRA techniques and a better understanding of human errors, including their causes, manifestation and consequences. The nineties saw a maturing of some of these HRA techniques and a broadening of models of human error to account for organisational influences on error and, more recently, maintenance error and errors associated with automation.

Details of the present human error theory and practice are reviewed in the previous section and it would appear that there is sufficient knowledge from other domains and from psychology and human factors to attempt to develop a human error modelling approach in air traffic management.

A review of error taxonomies, models and classifications has been undertaken throughout a variety of literature and it has been established that thirteen areas of human performance

and fifty-three approaches within these various areas should be considered within this research. A summary of all the approaches can be found in Table 3.

Table 3.1: Review of error taxonomies, models and classifications

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
1. **Task-based taxonomies** – these classification systems state what happened, e.g. fail to detect conflicting aircraft. Such taxonomies can be generic or contextual.	Error Modes (Swain, 1982; Swain & Guttman, 1983)	Error mode taxonomies, which state what happened are necessary but not sufficient. This is because they do not give enough causal information on why the incident happened, or how it happened. The Error Modes are necessary but often these modes do not go deep enough to render a useful understanding of the human contribution to the incident.
2. **System-oriented taxonomies** – these taxonomies also determine what went wrong, but are more system-oriented than pure human-oriented approaches. Errors are considered that can affect the system during maintenance, prior to an event, during it, those making it worse, and the recovery actions necessary.	Spurgin, Lydell, Hannaman and Lukic (1987)	Few single errors lead to significant incidents – more likely there is a concatenation, or a chain of errors and events. Any model must be able to capture the complete chain of events and facilitate a balanced appreciation of the causal contribution of each element in that chain. Currently maintenance or latent errors do not play a significant role in current ATM human errors, but as next generation systems are brought in which are more heavily reliant on software systems, maintenance and latent errors are more likely to play a part in incident causation

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
3. **Communication system models** – a range of models and taxonomies exist on communication, dealing with aspects of the message, the medium and the expectations of the sender and the receiver. It should be noted that communication models and theories do not always sit easily within other larger frameworks such as information processing models.	Lasswell Formula (Lasswell, 1948; Braddock,1958) Linear Model (Shannon & Weaver,1949) Grayson & Billings (1981) Cushing (1994/5) Helmreich & Merritt (1998) Westrum (1995)	Communication is obviously central to ATM and therefore models must be able to focus on this aspect of the task, whether today's task using radiotelephony (R/T) or the future tasks where there will be more reliance on datalink technology.
4. **Information processing models** – the information processing tradition has been the dominant model of human performance in psychology and human factors for some time, and is perhaps the most useful model for industrial applications. As can be seen from the next column the approach has developed over a large number of years. Central to the model is information input to the human, which is perceived filtered and	Fitts (1954) Miller (1956) Broadbent (1958) Welford (1960) Payne & Altman (1962) Berliner, Angelo and Shearer (1964) Martiniuk (1976) Wickens (1984,1992) McCoy & Funk (1991)	Information processing has proven one of the more useful psychological models of performance in various industries. Its basic emphasis on input, thought, output and feedback is useful for explaining behaviour and also informative for more practical considerations such as designing new displays, etc. The individual components of the information processing model (e.g. working memory) could be used to structure understanding of how errors occur in the human, leading to ways of reducing error potential or increasing recovery potential. However the usefulness of identifying team errors in a similar way is untested.

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
processed, with 'thought' (e.g. memory, judgement and decision-making) occurring inside the human via memory and other cognitive functions, and then external actions (e.g. physical actions and communications) are the result.		
5. **Symbolic processing models** – this is a rival to the information processing tradition, and considers humans as symbol manipulators. This approach is more 'cognitive' in its orientation, and considers the human as having reference 'mental models' of the world and how things work, and hence how to perform. This approach has some intuitive appeal in that many controllers do indeed talk of having a mental 'picture', without which they cannot properly control air traffic.	Newell & Simon (1972) Schmidt (1975) SRK Model (Rasmussen, 1981) Murphy Diagrams (Pew, Miller and Feehrer 1982) SHERPA (Embrey, 1986) Slips, Lapses, Mistakes and Violations (Reason, 1990) GEMS (Reason, 1987) Action Slips (Norman, 1981) Seven-stage Model (Norman, 1986) CREAM (Hollnagel, 1993) SMoC and COCOM (Hollnagel, 1993)	Symbolic processing models have helped several industries understand the nature of error, particularly within the more cognitive aspects of performance, for instance associated with errors of decision-making and misdiagnosis. In particular this theoretic tradition has led to the definition of a set of taxonomies that together explain error: error detail (what happened?); error mechanisms (in which cognitive functional area did the error occur?); information processing level (how did the error occur psychologically, and contextual conditions (what factors caused and contributed to the error?). The symbolic processing models (especially those by Rasmussen) have therefore laid the foundation for a set of structured taxonomies, and indeed have informed other industry taxonomic approaches (nuclear -power).

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
6. **Situation Awareness (SA) approach** – this approach has been influential in aviation systems, particularly military aviation. The approach states that the operator (pilot or controller) needs to have SA to perform their tasks effectively. SA comprises three levels: awareness of key elements in the situation; comprehension and integration of those elements to form a coherent understanding (picture) of what is going on and extrapolation of this understanding to the future to allow planning and strategic/tactical decision-making and action. This approach has obvious synergy with ATM and concepts such as 'the picture' of the air traffic controller.	Jones & Endsley (1996) Isaac and Ruitenberg (1999)	SA can be seen as either a process (i.e. how is situation awareness maintained?) or a product (what is the controller's current situation awareness or picture?). This ambiguity of the approach has led to some difficulty in assigning its role in supporting ATM system development, especially since the product interpretation becomes synonymous with the 'picture' concept already accepted in some parts of the world. What is clear, however, is that some errors do occur which can be neatly explained or categorised by SA approaches. It is also important to note that this approach has the potential to include team aspects as often errors occur when individuals have differing SA within a team structure.
7. **Signal detection theory** – This approach has grown largely out of the domains of inspection and vigilance. It is a well-proven model in these domains, focusing on the	Bisseret (1981)	This approach has partial relevance to ATM, since the controller must detect signals from a relatively noisy background (the radar screen) and must remain vigilant. ATM systems also now have alarms (Short-Term Conflict Alert -

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
human as a detector of a signal against a background of 'noise'. The human can also be subject to false alarms, and the rejection of actual signals because they are believed to be false alarms.		STCA) of which a proportion will be false alarms.
8. **Error of commission models** – these approaches try to address the growing problem of unusual and (usually) unintended acts that have been the cause of a number of incidents in other industries. They also relate to complex and unforeseen interactions in highly complex and otherwise well-defended technological systems.	PHECA (Whalley, 1988) PREDICT (Williams & Munley, 1992) EOCA (Kirwan et al, 1994, 1996) ATHEANA (Cooper Ramsey-Smith, Wreathall, Parry, Bley, Luckas, Taylor and Barriere, 1996)	Errors of commission may become more important as ATM system complexity and system inter-dependencies increase with advancing technology and controller support. However this type of model is also relevant when assessing the contribution of individuals in a team environment.
9. **Violation taxonomy** – violations are seen when the operator knowingly contravenes a rule, either because it may be necessary or expeditious to do so, or for other reasons. Violations have caused a number of serious incidents in other industries.	Mason (1997)	Since violations have been found to occur in most other industries, it is wise to ensure that any ATM model can at least account for them in its structure.

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
10. **Contemporary accident theory** – Recent work in aviation and other domains has been focused on the nature of accidents, and in particular their multi-causality. The main implication is that there is no single solution for most accidents, and the antecedents of full-scale accidents are most often deeply rooted in the organisational structure, safety systems and safety culture. The main implication is that there is no single solution for most accidents, and the antecedents of full-scale accidents are most often deeply rooted in the organisational structure, safety systems and safety culture. These approaches aim to take information from specific incidents and determine the deeper organisational 'health' problems. Arguably if these can be identified and rectified, then not only can the specific incident's recurrence be prevented, but other, as yet	Reason (1998) Maurino, Reason, Johnson and Lee (1995) TRIPOD (Wagenaar, Groeneweg, Hudson and Reason, 1994) BASIS (O'Leary & Chappell, 1996)	The implications for this research are complex, since safety culture is still a developing field without clear understanding. It is advisable that any modelling of team error should try to incorporate organisational causes into its structure. The potential for this model to be combined with the models of human performance would be an advantage as only in this way would a clear analysis of team dynamics be realised.

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
unseen potential incidents, could also be prevented.		
11. **Other industry approaches** – A number of specialised taxonomies have been developed which have a similar idea to the proposed research. HPES and NUCLARR are both nuclear power related and CORE-DATA is multi-industry in its application.	HPES: Paradies & Busch (1988); Kim (1997) NUCLARR (Gertman, Gilmore, Galtean, Groh, Gentillon and Gilbert, 1988) CORE-DATA (Taylor-Adams & Kirwan, 1995)	HPES has been fairly successful in its implementation and impact. CORE-DATA represents one of the main systems under development at the moment, and is also information-processing based and utilises a set of interrelated taxonomies. It utilised an equipment taxonomy and a task or action taxonomy, and its causal factor listing is hierarchical.
12. **Other transportation approaches** - Although most practical error insights and resultant techniques have been gained from the heavy industries such as nuclear power, chemical and offshore petrochemical industries, work has also occurred in other transportation areas, such as maritime, space, and aviation. The European Space Agency developed an initial approach to human error, and there has been significant analysis of shipping casualties over the years.	Drager, (1981) ARTFUL Decision-maker (O'Hare, 1992) Closed Ring Model (Pariès & de Courville, 1994) Error in Incident Sequence (Ramsey, 1985) Wiegmann & Shappell (1997)	Most of the work in these areas has been very focused on their own industrial context. ATM, is to an extent, a unique industry since it has some properties which are similar to process control, and others which are more similar to dynamic transportation systems. Nevertheless, there may be some features of these models that may allow a better understanding of team roles in a dynamic context.

Human Error Approaches	Taxonomies, Models and Classifications	Explanation
13. **Air traffic management models** – Only two models of human error were identified which were specifically focused on the ATM domain. The first was a model of incident causation, based on research by Welford (1960), Martinuik (1970) and Reason (1998). This model presents a useful framework for considering how incidents happen and the interrelationship between different levels of causes. The other model is a specific taxonomic set designed to analyse the error contribution to ATM incidents. This technique followed the work with CORE-DATA and SHERPA, and is also based around an information processing framework.	Triptych Pyramid Model (Isaac,1995; Isaac & Ruitenberg, 1999) TRACEr (Shorrock, 1997; Shorrock & Kirwan, 1998)	The Triptych Pyramid Model usefully relates some of the contemporary accident theory specifically to ATM, including the role of latent errors and organisational issues. The TRACEr model is information processing based, and has several taxonomies of errors derived from human error theory.

The links between all the approaches can be graphically seen in the table in Appendix A. However, as has been explained, no model or approach has yet been developed which is specifically for the air traffic management environment. The next sections address this problem.

In order to determine the most appropriate model for assessing error in ATM and the association with team dynamics, the present and future air traffic management context should be reviewed.

3.2 The present and future air traffic management context

A model that can be used to determine error contributions to incidents, must be able to classify the complete range of errors that can occur in ATM, with particular reference to teams. This applies not only to current ATM but also to the developments that are likely to be implemented in the medium-term future (over the next 10-15 years).

The CORE-DATA system (Taylor-Adams & Kirwan, 1995) reviewed in Table 3.1 utilised not only error descriptors but also descriptions of the tasks, behaviours and equipment involved in the error scenario. Such considerations can add context to the classification and become potentially useful when trying to learn from incidents. Alternatively, when examining incident trends it may be found that certain significant errors are concerned with regard to certain functions. Gaining such insights relies on classifying the incidents according to their ATM context in the first place. This effectively means that the following three aspects of the error/event/incident must be systematically recorded:

- What the controller was trying to do - the ATM task;
- How the controller was trying to achieve it - the ATCO behaviour;
- What the ATCO was using to achieve it - the equipment.

If these three aspects are systematically recorded, then the resulting error analysis will be far more useful, particularly in relation to team dynamics.

3.2.1 Current air traffic management tasks, individual behaviour and equipment

For current ATM systems any model must generally be able to deal with the following:

Table 3.2 : Tasks, behaviour and equipment in ATM

Tasks	Behaviour	Equipment
• traffic management and conflict detection	• anticipation	• radar screen
• conflict resolution	• planning	• ancillary screens, strip bay, traffic flow information,

		etc
• co-ordination	• situation assessment	• computer
• handling of emergencies	• monitoring	• a touch input device
• advice to aircraft (on meteorological conditions)	• detection	• a pointing device (mouse; track ball, light pen)
• management of pilot-initiated communications	• evaluation	• a paper strip board (and strip printer)
• management of aircraft in stack	• resolution	• panels associated with telecommunications
• guidance (on airports)	• communication	• telephone and radiotelephone
• arrival management	• verification	• headsets
• clearance delivery	• decision-making	
• planning of taxi routes		
• departure management		

3.2.2 Future air traffic management

The future ATM environment will lead to changes or a shift in the human's role and tasks. However, it is not clear whether this shift will result in new functions or individual behaviours. Instead, future impacts may simply result in different emphases, for example, electronic strips and datalink will generally have the same functions as current paper strips and datalink, with some additional functionality (enabling electronic co-ordination between radar and planner; enabling the controller to understand better the aircraft's intent via datalink interrogation of the aircraft's Flight Data Processing System (FDPS). This extra functionality will generally be subsumed within current functions such as management of traffic and conflict detection, using conventional (current) individual behaviours (anticipation, evaluation) but it will certainly affect the team dynamics and task allocations and responsibilities. The significant difference with some of the more advanced functionality is that the function may shift from being a human-implemented function to a computerised one,

with the development of conflict detection support being a prime example. In such cases, although the function is the same, the role has changed.

What will also change are the procedures and the interface with equipment.

A fundamental concern over future automation is the degree of trust that controllers will have in such systems and in their team members. Therefore any model must be sensitive to the following evolving aspects of air traffic management:

- the shifting role of the controller - with respect both to automation and pilot autonomy;
- changes in the controller's 'picture' and impact on situation awareness;
- issues of trust and complacency with respect to automation;
- the potential shifts towards knowledge-based errors;
- team and organisational aspects.

Additionally, a significantly difficult time for air traffic management will be when a new technology is brought in gradually or in stages. An example would be datalink, since some aircraft will have datalink capabilities before others. The controller may then have two additional tasks: determining which aircraft have datalink and which do not, then selecting the appropriate medium for communication. Although this sounds trivial it is not as the controller and the team members will have to keep switching from one 'mental modality' to another, often under significant workload pressures. It is for this reason that a contemporary approach to modelling error in the ATM environment must be pursued. A description of this approach follows.

3.3 An enhanced model of human information processing

A new enhanced model of human information processing within the ATM structure will be offered. The rationale behind this is that the pervious attempts at similar models have fallen short of the complexities of individuals within the team. There have been two main methodologies within this domain. The first, which has the longest tradition, is to attribute the error(s) made by an individual to the final action in the occurrence/ incident or accident. This in itself is not wholly wrong; although the blame culture which resides in the ATM industry and other similar domains has prevented much progress in the proactive aspects of safety improvement. However it is clear from any cursory glance at incident/accident investigation that the individual

at the penultimate and final stages of an error chain is often not the individual who has paved the way for the final outcome. It is also true to say that rarely has the individual in this case been examined in terms of the dynamic interaction with others at the time of the incident.

The second and most contemporary approach has been to take a much more global view of error causation and investigation and advocate that the system is often the weakest link in the chain of events and that in many catastrophic incidents and accidents it is the organisational factors which create these situations. In other words at international, national and regional level there are individuals who create unsafe situations. Also the company and organisation often play a part in compounding unsafe situations or create them in a hostile economic climate.

From the review of literature regarding error modelling it can be ascertained that the model of human information processing provides a sound underlying approach for a human error classification system. This model of information processing appears to be the most suitable model, if adapted to make it more applicable to ATM. Most models comprise a number of information processing stages and functions. These stages and functions, along with adaptations to the model, are briefly described in the following paragraphs and illustrated in Figure 3.1.

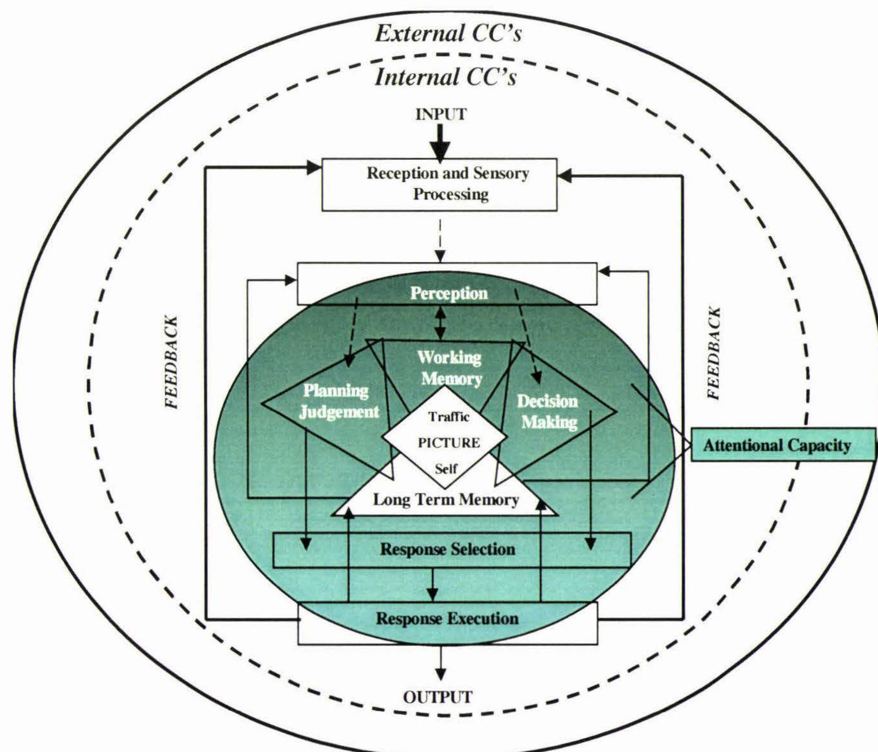


Figure 3.1 : An enhanced model of human information processing

The following elements can be found in this model:

Reception and Sensory Processing: this stage involves the initial reception and sensory processing of external information (radio-telephone call from a pilot) and internal information (the 'feel' of a switch). Information from each sensory modality can be retained for a very short period of time (less than eight seconds) without any attention in a 'short-term sensory store'.

Perception: sensory information is detected, then identified or recognised, based on an association with long-term memory – a large store of relatively permanent information. Thus, a controller may detect an aircraft 'label' on the radar display, and then identify the aircraft by using other information, such as call sign. Example errors of perception include misidentifying an aircraft on a radar display or a paper flight progress strip, or failing to detect a pilot 'readback error', where a pilot fails to correctly read back a controller's instruction.

Working Memory: working memory refers to the temporary encoding, storage and retrieval of verbal and spatial information. For example, working memory is used to retain the contents of a pilot's transmission or a conversation with another controller, to perform mental calculations, or to remember to do something in the near future - 'prospective memory'.

In the enhanced model of human information processing used in this research working memory follows 'sequentially' from perception. This is a departure from other models which usually show decision and response selection following from perception. The rationale for these original models was that it was assumed that a decision was made to either store information in working memory or select a response. However, whilst a decision to select a response may have to be made, committing information to working memory is often automatic in the first instance. In the ATC environment controllers may then decide how long to try to hold information in working memory, or decide to try to recall something at a specific time in the future. Working memory is thought to contain part of what is traditionally referred to as 'the picture', (the controller's mental representation of the traffic situation) In the enhanced model this is termed 'ATM picture'. However, controllers also have thoughts about themselves and their ability to cope with the traffic situation. This includes factors such as confidence (in self and others), perception of workload and how situational aware they feel. In the enhanced model this is termed 'self-picture'.

An example of working memory error includes forgetting to transfer an aircraft to the next sector controller and forgetting the details of a co-ordination with another controller.

Picture Update Process: the 'picture update process' represents the flow of information used to update the controller's ATM picture and is unique to the ATM environment. Information from perception, long-term memory, judgement, and from planning and decision-making is used to update the picture:

- Information from perception - current aircraft movements on the radar display, flight progress strip markings and current pilot transmissions.
- Information from long-term memory - recalled procedures, previous briefings.
- Information from judgement, planning and decision-making - judgements regarding climbs, descents, and turns, decisions about whether to act on a conflict alert.

Long-term Memory: long-term memory is a "storehouse of facts about the world and how to do things" (Wickens, 1992, p. 211). This 'storehouse' includes information derived from training, procedures and briefings. An error of long-term memory may occur following a change in procedures, when a controller can incorrectly revert to the previous and well-learned procedure.

Mental Model Update Process: the 'mental model update process' is the flow of information from working memory to long-term memory. The controller's mental model is updated by new information from working memory, judgement, planning and decision-making.

Planning, Decision-making and Response Selection: previous models contained an information processing stage called 'decision and response selection'; this has been divided into two separate renamed processes in the enhanced model described:

- planning and decision-making: these reflect more explicitly the processes of judgement, projection, prediction and planning used in ATM. 'Judgement' here refers to judging the required heading,

climb, descend or speed, etc., to achieve separation. A controller may, for example, misjudge a required climb. An example of an incorrect decision may be to ignore a conflict alert based on the assumption that it is a false alert.

- response selection: once the controller has made a decision a response is selected.

Response Execution: response execution involves the physical actions or speech that are used to effect a decision. Hence, errors of response execution include 'slips' such as writing or saying an unintended Flight Level.

Attention: most of the processing that occurs following reception and sensory processing require attention to function efficiently. Attention is shown as the green shaded area in Figure 3.1. Wickens (1992) describes attention both as a 'searchlight' that selects information sources to process and as a commodity of 'limited availability'. Learning and practice reduce the demand for attentional resources.

Internal and External Contextual Condition: the individual influences on the controller in this model are found in the two surrounding spheres; these being the Internal and External Contextual Conditions. The internal contextual conditions include the working environment, the rules, procedures and working practices of the system and the external contextual conditions include the organisational and management influences in which the system is embedded. The dynamics of the team are thought to be those concerned with exchanges between the individual and their immediate internal contextual conditions or environment.

CHAPTER 4. AIR TRAFFIC MANAGEMENT TEAM ERROR CONCEPTUAL FRAMEWORKS

4.1 Teams and teamwork

Teams, it is said, are more than collections of individuals and teamwork is more than the aggregate of their individual behaviour (Bass, 1980). One can identify the definition of a team from many other researchers in this area as ' the set of two or more individuals who interact dynamically, interdependently and adaptively toward a common goal or objective'.

Early writing in ergonomics and human factors rarely mentioned these issues of team or group. A text by Morgan, Chapanis, Cook and Lund (1962) mentions the arrangement of groups of men and machines, and is concerned with the layout of spaces used by more than one individual, rather than the communication and co-ordination between the members of the group. Most of the work in team work comes from the research in organisational psychology and is influenced by theories of group dynamics. However the literature addressing teams and groups is quite new and full of anomalies when considering the definition of both teams, groups and their dynamics.

The difference between groups and teams is something of a problem area. Any difference is at best not obvious and is not helped by the inconsistency in the research. While some researchers (Orasanu and Salas, 1993) do make a distinction, others (Sundstrom, DeMeuse and Futrell, 1990) regard the terms group and team as interchangeable. Often researchers highlight the differences between a group and a team, or describe the characteristics of teams instead of defining the team per se. Orasanu and Salas (1993) attempt to describe the fundamental differences by stating "teams consist of highly differentiated and interdependent members, groups on the other hand consist of homogeneous and interchangeable members" (p.328). The most critical difference being the degree of differentiation of roles of task-relevant knowledge and the degree of interdependence. Finally, Johnson and Johnson (1987) discuss the issues of the team as a special case of a group whilst in other related literature, Chu and Hadfield (1997) use all these terms interchangeably.

For the purpose of this research the term 'team' will be discussed in relation to the air traffic management environment, however further refinement of this definition may be appropriate in the light of the experimental findings.

To understand effective team performance or 'teamwork' one must understand how groups of individuals function to produce effective synchronised output, rather than just summed or aggregated responses (Steiner, 1972; Hackman and Morris, 1975; Fleishman and Zaccaro, 1992). From the literature it can be seen that the characteristics which seem to distinguish teams from small groups include the following:

- multiple sources of information
- task interdependencies
- intensive communication
- co-ordination amongst members
- task relevant knowledge
- specialised member roles and responsibilities
- adaptive strategies to help dynamic change

The first serious attempts to study team processes began in the 1950s and 1960s, with the focus largely on military teams and team processes that enabled them to function effectively under conditions of extreme time pressure, high stress and with ambiguous or incomplete information.

During the last half century theories have been offered that encompass many of these different perspectives. Most theories have incorporated a general input-process-output approach, whereby certain variables are fed into the system, team process follow and team output results. Some models also incorporate dynamic change through feedback loops, coming primarily from the outside and feeding back to the input. This reflects the idea that is found in individual information processing and suggests that a team operates like several individual information processors. However many researchers would also conclude that the team output, although dependent on the individuals, has a more complex dynamic linked with interaction which is a defining characteristic of the team (Gill, 1984).

Performance may focus on either team accomplishment – referred to as product, or the manner in which the team behaves – known as process. In terms of information processing the areas of communication and co-ordination are usually regarded as important processes or team skills, whilst in the affective area, team spirit or

cohesion may impact team performance indirectly (Annett, 2000). These issues can be illustrated in the following figure.

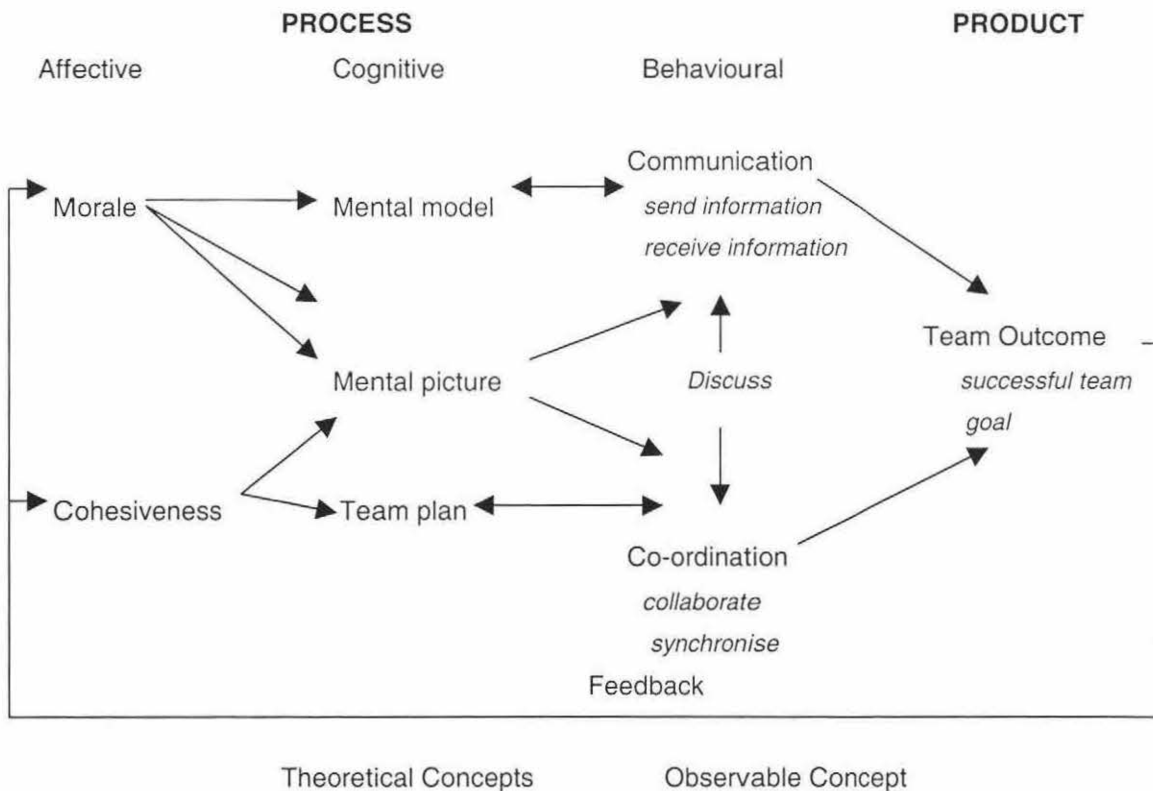


Figure 4.1: A model of teamwork [adapted from Annett, 2000]

In addition to developing theories and models, team researchers have tried to identify those critical traits or skills that enable teams to co-ordinate, communicate, strategise, adapt and synchronise task relevant information so they can fulfil their goals. In the 1970 and 1980s, research focussed on orientation, resource distribution, response co-ordination and motivation (Nieva, Fleishman and Reick, 1978) team morale (Ruffel-Smith, 1979; Zander, 1971,1975) and group productivity (Steiner, 1972). In the 1980s the emphasis was given to collective self-efficacy (Bandura, 1986) implicit or explicit co-ordination activities (Kleinman and Serfaty, 1989; Gill, 1984) and team cohesion (Mudrak, 1989).

Finally in the 1990s, the most significant teamwork competencies were thought to be mutual performance monitoring (Hackerman, 1990), belief in the importance of teamwork (Gregovich, Helmreich and Wilhelm, 1990), collective orientation (Driskell and Salas, 1992), adapting to novel and unpredictable situations (Prince and Salas, 1993), assertiveness (Smith-Jentsch, Zeizig, Acton and McPherson, 1998) and

predicting others behaviour (Hodge, 1995; Volpe, Cannon-Bowers, Salas and Spector, 1996).

The team research undertaken in the 1990s has evolved to a great extent in the development of theory associated with shared mental models (Cannon-Bowers, Salas, Converse, 1993). Mental models are described as knowledge, structures, cognitive representations or mechanisms which humans use to organise new information, to describe, explain and predict events (Rouse and Morris, 1986). It is suggested that shared mental models allow team members to implicitly and more effectively co-ordinate their behaviours by recognising individual roles, responsibilities and the information needs of others by monitoring their activities, diagnosing problems and supporting them with information or active help, (Orasanu, 1990).

It can be seen that many different dimensions and categorisations of team work processes have been proposed. Based on an extensive review of the literature seven main components of successful team work can be defined:

- Communication — verifies information
acknowledges messages
- Co-ordination — passes performance relevant data to other members
facilitates the performance of other members' work
- Monitoring — is aware of other team members' performance
recognises when a team member performs correctly
- Team leadership — explains to other team members what is needed
listens to concerns of other team members
- Team orientation — assigns high priority to team goals
participates in all relevant aspects of the team
- Feedback — responds to information on request
accepts suggestions from others

- Back-up behaviour takes over from another member when they cannot perform
  helps another member correct mistakes

Despite these theories of team performance, which have allowed a greater understanding of how teams work together and what affects their performance, few if any have tackled the issues of team error and its management. Many models and approaches indicate the variables which must be inherent in successful teams (Zander,1971, 1974, 1975; Gill, 1984), but few have looked at the issues of error recognition, detection and management.
In order to determine the possible teamwork skills and traits which allow successful air traffic control performance – if indeed they do differ from other groups or teams – the issues related to team performance in ATM should be reviewed.

4.2 Team performance issues in air traffic management

In the past ATC was considered mainly as an individual activity, but more recently, and with changes in roles and complexity of activities, the work of the individual controller has become more dependent on teamwork. In ATC the attempt to define a team has been rather difficult. The term 'team' is used in many European countries to describe the control staff or groups working physically together in one ATC unit such as Aerodrome, Approach and En Route Control (ACC). The criteria to describe a team ranges from controllers working in the same sector or controllers working in different sectors but belonging to one particular shift or watch. Controllers usually become members of a team after training and check-out, and stay in the team often for the rest of their career. Teams are often self-organised structures with specific cultures, rules and roles, and are highly protected from the outside world.

All controllers have safety critical teamwork relations with the aircrews entering and leaving their sectors of responsibility. Amongst controllers the smallest teamwork cell can be described as those controllers and flight data assistants working physically together in the same operational unit. Teamwork relations also exist between controllers of adjacent operational areas and between controllers of different ATC units. Teamwork aspects in a wider scope also occur between controllers and any other operational staff such as flow management, supervisors and ATM support staff.

The air traffic control team or watch is a highly structured group and as such has been discussed as an environment in which a number of socio-psychological, personality and group interactional variables are potentially related to team effectiveness. As well as these variables there are obviously the individual cognitive activities which can be detailed within the different ATC functional areas. It is therefore also worth noting the activities within these areas which are co-ordinated or shared with other members of the air traffic control team. These can be summarised in the following table.

Table 4.1 : Functional positions and their co-ordination activities in air traffic control

Co-ordination activities	Ground control	Tower control	Area control	En-route control
Communication	✱	✱	✱	✱
Leadership			✱	✱
Strategic planning	✱	✱	✱	
Tactical planning			✱	✱
Decision making		✱	✱	
Situation Awareness	✱	✱	✱	✱
Assertiveness	✱	✱	✱	✱
Adaptability	✱	✱	✱	✱

4.2.1 Team dynamics

All successful teams have leaders and the ATC environment is no different. What is unique in this environment, however, is the fact that there are two types of leadership. As well as formal leadership given by the company, supervisor, centre manager etc, (hierarchical) there is also the leadership responsibility created by 'situational' factors (functional). These situational factors would include such responsibilities as training, the roles of radar position versus the planner, and the fact that in many centres controllers will take on responsibilities whilst the named supervisor or manager is formally involved in other projects; this is particularly noticeable during changes within the organisation.

Because of the nature of ATC, leaders usually also possess the skills to delegate responsibility, have strong decision making and communication skills and have developed the skills of conflict resolution. Those who work for good leaders also mention the fact that they are fair, sympathetic, empathetic, knowledgeable and

communicate well with all members of the team including management. These skills and abilities are quite clear. However, what is not so clear, is the 'situational leadership' which nearly all controllers will experience.
Situational leadership is the skill to influence others on the basis of local knowledge and/or personal abilities and characteristics. This type of leadership is more tacit, that is it evolves from less tangible things which may include the personality of the individual or simply acquired knowledge and skills (not always restricted to the ATC environment) which a person has. These 'leadership' qualities are not always given by the organisation, but often the organisation recognises these natural or developed skills and uses them in a less formal way than management or supervisory roles - for instance, inviting the individual on to a working group in a new technical development.

As with all successful teams, there are also followers, and ATC is no exception. Followership can also be classified as a skill and is associated with the willingness to co-operate with the others in the team. Followers allow others to make decisions and often subordinate their personal preferences, but in good teams these people will not necessarily agree with the leaders in all situations. Those in a followership role need to use assertiveness and use the skills of advocacy, especially when risky decisions are being made.
Effective followers will analyse the situation carefully and speak out for the course of action that they feel is best. They will use assertive behaviour and act in a timely way, questioning decisions which they do not understand or disagree with.

The role of the supervisor in ATC is important and often complex. The position is one that is given by the organisation and normally those in this role have experience and knowledge. Some supervisors will also be current on position, which also complicates their role because they have to divide their time, and in doing so, they can find that they lose confidence in their ability to remain current on position. Others are purely supervisory, without current ratings on position, which again can lead to problems of credibility. Supervisors are also part of the team, even if they do not work on position, and therefore it is important that they create an acceptable gradient of leadership authority over their team's assertiveness and advocacy roles. This suggests that although they are known to have the ultimate responsibility they should also create the opportunity for team members to question and critique their decisions.
The problem of different roles in the controlling environment often creates what can be called paradoxical situations. This refers to the fact that some roles are not well

defined and therefore have different meanings to different individuals. A 'paradoxical' situation is usually made up of contradictory elements and can be illustrated by the example of a young controller who is appointed in a supervisory capacity along side older and more experienced controllers.
The position of On The Job Training Instructor (OJTI) can also cause ambiguity of roles. This is because of the way ATC is structured and it is again not uncommon for a OJTI to be training a more experienced colleague.

These phenomena are found in other non-hierarchical and decentralised decision making environments and are one of the key factors of high reliability organisations. The reasoning behind this situation is that in order to allow rapid decisions of a safety nature to be made, authority needs to be devolved to those who are closest to the problem. These decision making behaviours can be observed in air traffic control rooms, where supervisors and controllers may switch responsibilities when necessary and where informal teams are often formed to exchange advice and manage highly safety critical situations, Sagan (1993).

These team roles may cause, as well as solve, stressful situations within ATM. Many teams create pressure within their own structures by trying to manipulate more free time by opening less positions whenever possible. This can be a problem at team level but may also create individual problems as members of the team struggle to handle more traffic, possibly taking more risks, and with a reluctance to ask for assistance.

Another issue when discussing teams in ATM is the development of a 'good atmosphere' in which to work. So often in this environment, controllers are critical of their team members, which is usually damaging to the working situation. This is not unique to ATC and can be found in all teams in which high professional behaviour is constantly expected and demanded.

4.2.2 Working with other teams

There is a fundamental belief within the ATC community that other teams from other sectors or units do not perform in the same way or to the same standard. The main reason for these beliefs is that the teams concerned rarely meet each other but are constantly talking to each other with requests and instructions. In many cases these requests cannot be accommodated or have to be delayed, changed or cancelled.

This is a rather negative communication situation and leads to the belief that the other teams are being difficult - after all, the facts behind these decisions are usually never known. This difficulty is more the effect of human behaviour rather than faulty decision making, and is just as problematic in the communication with pilots.

In order to establish how these ATC dynamics affect the potential error prone situations, it is important to establish exactly what tasks are undertaken in relation to the team structure.

4.3 Development of a team error model in air traffic management

Although there is now a large body of knowledge within management and the sports environment with regard to team performance, there is a dearth of information with regard to teams and team performance within the air traffic management system. Recent research evidence would however support that the introduction of team training has had a long history within the airlines (Crew Resource Management - CRM) (Wiener, Kanki and Helmreich, 1993) and more recently in the ATC environment (Team Resource Management - TRM) (Barbarino, Woldring and Isaac,1999). However a closer look at those initiatives suggests that, although the subject of team performance and error is introduced, evidence of its nature as a team phenomenon is not explored.

It would seem important that, in order to identify those aspects of the ATM team which are the potential causal factors in occurrences, a systematic method of task analysis that can identify the important team skills[4] should be considered.

For en-route controllers a set of 'key tasks' (Redding, Cannon and Lierman, 1991) or 'core tasks' (EATMP, 1996) can be distinguished. These can be identified under the following headings.

Maintaining situational awareness	In order to maintain situation awareness (SA) en-route controllers have to 'have the picture'. This means that a mental traffic picture has to be continuously projected into the future and this anticipation has to be checked with the actual

[4] It should be noted that the emphasis of this model development will be in relation to a two person radar position; that is a radar controller and their planner. These positions are normally found in the area and en-route sectors, although it is true to say that many of the skills discussed would be found in all other controlling environments.

	traffic situations, Under normal working conditions the mental picture is initially built up when taking over position.
Receive and develop sector control plan	Flight progress information and traffic forecast have to be integrated into a future plan of the traffic situation, allowing a safe and expeditious flow of traffic. In many situations this can be referred to as 'conflict avoidance'.
Make decisions for control actions	This includes active decision making related to the development and revision of the sector control plan and are often triggered by pilot requests
Solve aircraft conflicts	This includes the provision of separation and solving of aircraft conflicts
Provide tactical air traffic management	Accepting aircraft, carrying out handover, providing pilots with relevant information, providing assistance in abnormal situations etc.
Other complementary tasks	These include briefing and update of the working knowledge of en-route controllers.

The overall principle of ATC is ensuring safety, meaning that everything works according to the safety rules and procedures which are very prescriptive. There is also continuous checking of the whole situation for abnormal or unexpected events. This checking includes self-monitoring and team monitoring. In order to attempt to analyse the interrelations of the individuals in this situation, it would be useful firstly to consider a task analysis of individual controllers

4.3.1 Task analysis in ATC

All the above skills and tasks have underlying information processing activities or cognitive elements. In terms of an en-route controller, in particular, there are ten interrelated processes. The ten basic processes have been identified in an extensive intergrated task analysis research project by Eurocontrol (EATMP, 1999b). These ten basic processes are as follows:

Control process 1	- switching attention
Task process 1	- taking over position/building the mental picture
Task process 2	- monitoring

Task process 3	- managing routine traffic
Task process 4	- managing requests/assisting pilots
Task process 5	- solving conflicts
Sub process 1	- confirming/updating mental picture / maintaining situation awareness
Sub process 2	- checking
Sub process 3	- searching conflicts/checking safety
Sub process 4	- issuing instructions

The main control process – 'switching attention' in one situation is a sub-process of the 'solving conflicts' and 'managing requests' process, but in other situations it governs the whole action in the case of multitasking. These processes can be graphically illustrated in the following way to allow understanding of the interrelations within the ATC environment.

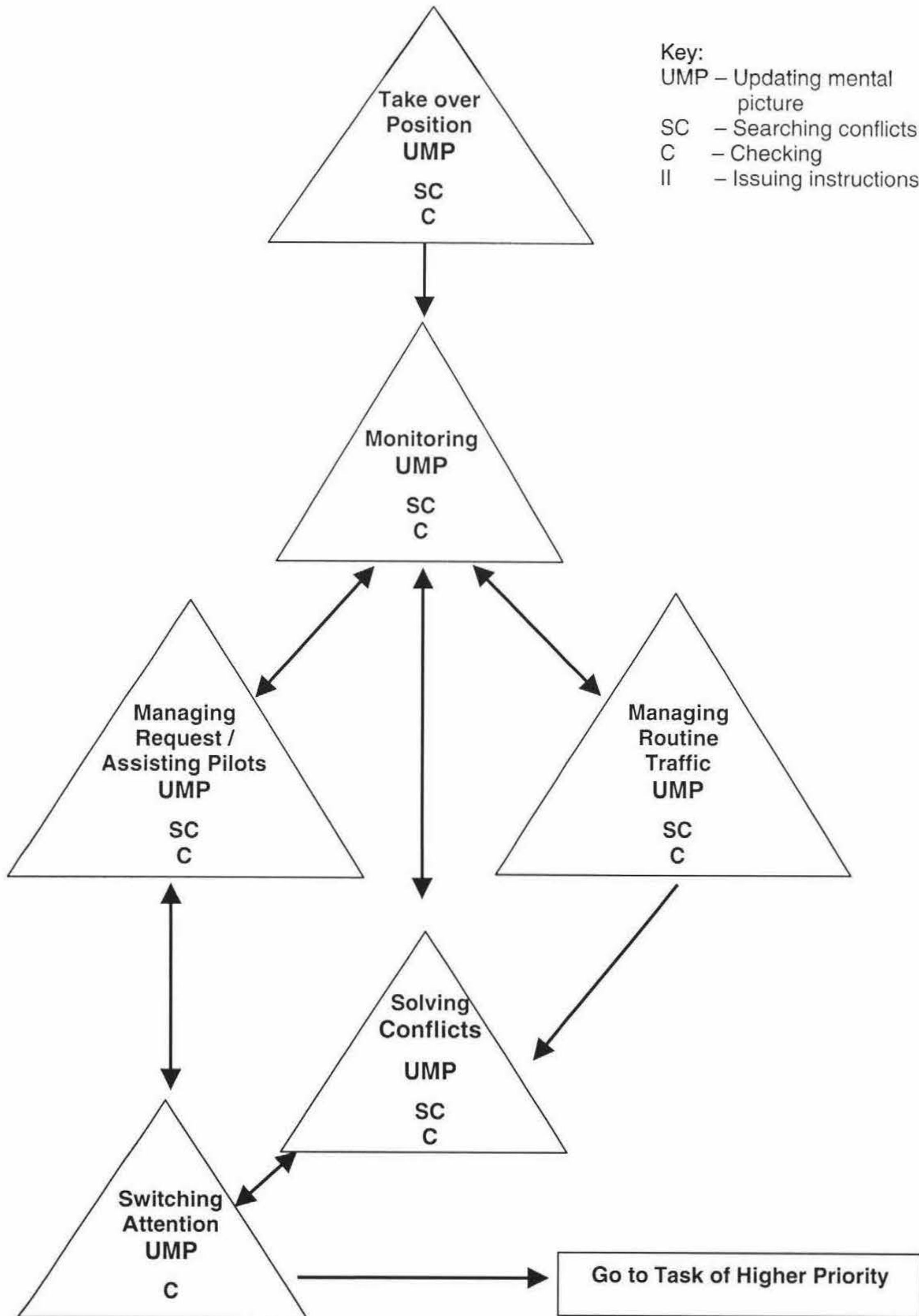


Figure 4.2: The interrelations of ATC task processes [adapted from EATMP, 1999b]

Although a task analysis has been able to identify the ten core activities and their interrelationships there has been no attempt to assess how these activities could be identified and assessed within the team working situation. Although it is known from observations in a New Zealand research activity (Isaac, 1994) that teams and teamwork was the second most important factor found in ATM, no task analysis activities to date have been able to elaborate these relationships.

4.3.2 Team tasks and processes analyses

It is suggested that if a detailed breakdown of each of the core tasks into their processes could be achieved, then it may be possible to assign team interactions. The following table indicates the breakdown of the core tasks which include the team related aspects. This is based on an adaptation of the individual task analysis methodology used in the Eurocontrol research (EATMP, 1999b).

Table 4.2 : Core task processes and the relation to team members

CORE TASK	TASK PROCESSES			TEAM RELATION
	Action	Memory	Decision	
Taking over position	• obtain shift briefing • scan radar and f.p.s. • monitor ongoing action • get briefing • checking • conflict searching • update picture • take over position	• retrieve sector scenario for actual conditions • integrate into mental model • confirm previous controllers plans • anticipate future traffic situation • develop a plan • plan a solution	• identify potential conflict	• related to supervisor • request information from out going controller • information given by out going controller • confirm with out going controller • does it match with out going controller • confirmation with out going controller
Monitoring	• update picture • conflict searching • solve conflict	• update sector plan	• action required • potential conflict expected	• communicate with planner/other sector

CORE TASK	TASK PROCESSES			TEAM RELATION
	Action	Memory	Decision	
	• manage request • manage routine traffic		• receive request	• communicate with pilot • communicate with pilot/other ATCOs
Managing requests/ Assisting pilots	• checking • conflict searching • deny or approve request • approve request / coordinate an alternative solution	• retrieve/ select short term sector plan/action plan	• evaluate workload of own and adjacent sector • time available • conflict expected	• contact next sector • issue instructions • issue instructions to pilots • co-ordinate and communicate
Managing routine traffic	• issue instructions or check conflict search • solve conflict	• activate script of handling routine traffic • retrieve/ select short term sector plan • update long term sector plan and update action plan	• instruction/ information necessary • potential conflict expected	• communicate with pilots • communicate and coordinate with pilots / ATCOs

CORE TASK	TASK PROCESSES			TEAM RELATION
	Action	Memory	Decision	
Solving conflicts	• monitoring • monitor aircraft • coordinate • update picture	 • retrieve routine solutions from 'conflict solution library' • active problem solving review / generate new solution • retrieve back up plan or solution	• potential conflict expected • action now • evaluate solution • best known solution • problem solved	 • issue instructions to pilots and ATCOs • discuss with ATCOs • discuss with ATCOs
Switching attention	 • checking • task of higher priority • set time window • integrate time window in sector plan • set reminder • switch to higher task priority • check task • complete task • set reminder	 • set mental reminder /update action hierarchy • update sector plan / action hierarchy	• review sector plan/ action • use current mental picture • review sector plan / action	

When considering the last column in the task breakdowns above, it can be seen that five of the six core tasks are associated with teamwork, either between the planner, supervisor, other sector controller or pilots. In terms of opportunities of team dependency, it can be assessed that each core task has differentiated team activities. Taking over position seems to rely on verbal communication, but to a greater extent on a shared mental model. Monitoring relies more on communication, but does have some reference to a shared mental picture. Both managing requests and assisting pilots and managing routine traffic seem to rely more on communication with some coordinating activities. Solving conflicts is dependent more on a shared mental model and picture, whereas the task of switching attention has no obvious team related activity.

As a result of the review of other team work research and the task analysis activity above, it is proposed to offer a new model of teamwork which might be suitable to act as a basis of work in the air traffic management domain. This model new is illustrated in the figure 4.3.
The model demonstrates the interactivity of the *team* or *dynamic set* within the ATM system. It shows that the most important issues, as taken from the previous review of ATM work, are co-ordination, communication and the picture or shared mental model. All these aspects are not only illustrated as 'stand alone' activities but the figure also tries to suggest where these activities overlap. It also demonstrates the interrelationship of these important issues of communication, co-ordination and the mental model. It is suggested that at the centre of these processes lies the opportunity to manage the errors which occur and to support the team in this safety critical activity. This model will be used in the third experiment when observations in the simulated ATM environment will hopefully be able to be mapped on to the suggested structure and assist in the development of insights relating to team error.

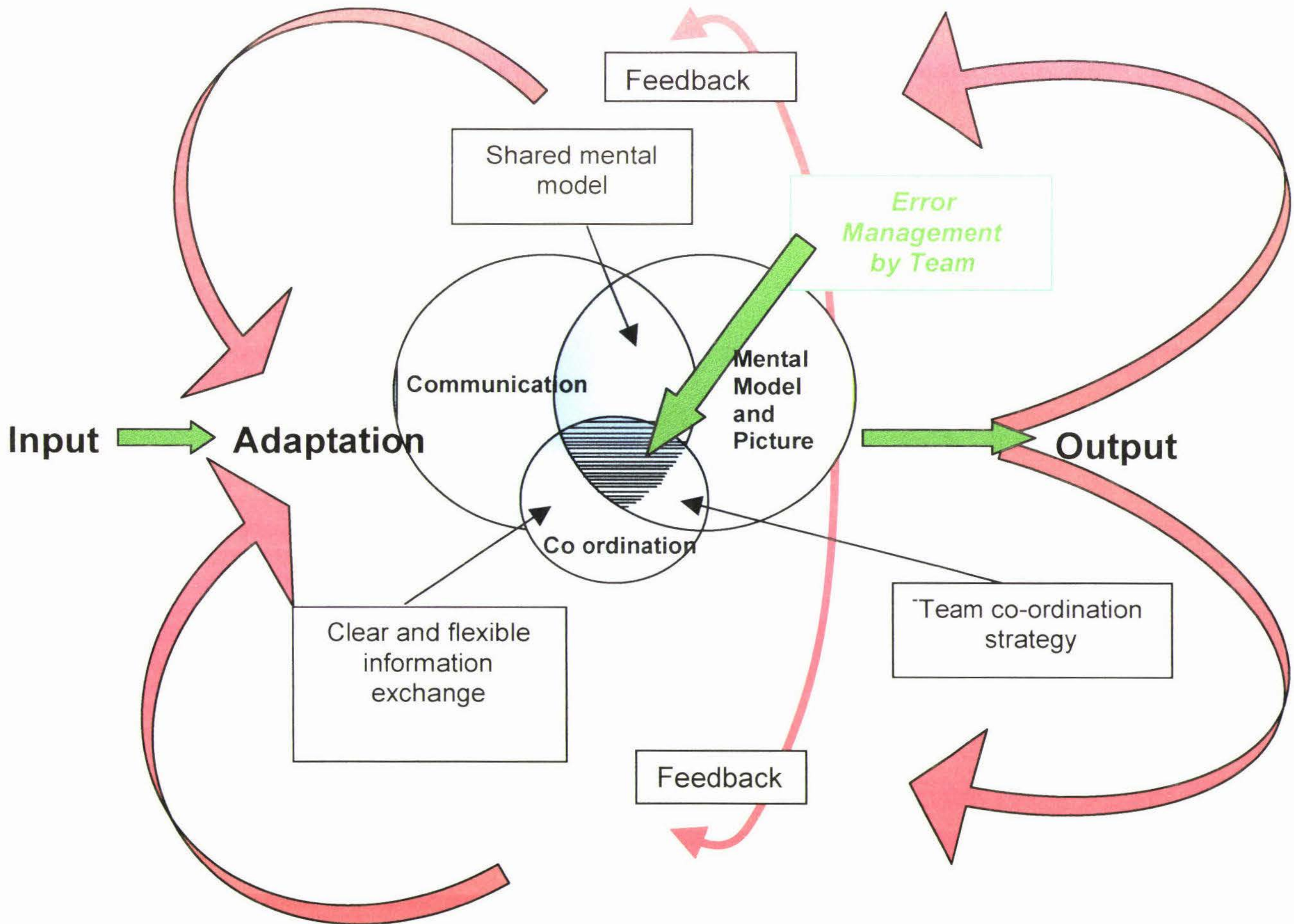


Figure 4.3 A new model of teamwork in ATC – Dynamic Sets

CHAPTER 5. EXPERIMENTAL WORK

The experimental work was designed to systematically evaluate the issues of human error within the air traffic management environment, particularly from the team standpoint. As there is so little research evidence with regard to team error in this domain, and its recognition, detection and recovery, it was decided to evaluate these issues in three distinct but complimentary ways, in three separate studies.

In the first study, a number of incident reports were used to ascertain the most problematic individual cognitive failures and their influence on the team, both of other controllers and pilots.

In the second study, it was thought appropriate to devise a questionnaire to elicit the views of active controllers with regard to error, safety and the team dynamics in air traffic management. The aim was to identify the most problematic areas which could be identified by the controllers themselves and to substantiate and elaborate the information from the incident data.

The third study used the information gained from the first two data gathering studies to formulate a way of recording the human errors found in the operational control situation. This final study used the information gained particularly from the issues found in the team dynamics, to try and evaluate whether the previous data was valid in the operational environment. It was particularly necessary in this final study to understand the real dynamics within the team situation and to evaluate the ways the members of the air traffic control team were able to recognise, detect and recover not only their individual errors, but those of other team members.

5.1 Study 1 – Analysis of human error in air traffic management incidents

The human contribution to errors has been frequently assessed as between 70-90%, Kinney, Spahn and Amato, 1977; FAA, 1990; Reason,1990) and the error rate in dynamic situations, such as flying, driving, and anaesthesiology, has been repetitively found to be approximately 2 or more per hour (Amalberti, 2001) However these seemingly high error rates hide the fact that humans are exceptionally good at detecting, controlling and managing the risks associated with these errors. These issues support the well known fact that very few errors or error chains actually result in an accident.

It was therefore thought appropriate in the first study to try and identify the types of human error which are typically reported within incident investigation. This activity is not reported in any literature and typically is fraught with several problems. Firstly it is known that very few incident investigation practices within the air traffic profession are standardised although in 1997 a document was published by the International Society for Aviation Safety Investigators (ISASI) with regard to incident investigation processes. Secondly, when reassessing the involvement of the human in incident and accident reports it is known that few investigations take account of the human performance limitations, and as such the details pertaining to these issues are, at best, scant. (O'Hare, 1992)

However, as this research did not allow the investigation of incidents in the 'live' setting, previously investigated cases of incidents were used. A large number of incidents were randomly chosen to be re-analysed from a human performance perspective. These incidents (all non fatal occurrences) were obtained from European countries (UK, Finland, the Netherlands, Sweden and the Upper Air centre in Northern Europe), the United States and Australasia. The approach used was an adaptation of the latest retrospective analysis technique which has been developed within Europe. The approach is known as the Human Error in ATM (HERA) technique and is based on both an extensive review of human error methodologies and classifications which have been developed in other professional areas. A summary of this approach is found in section 3.1.

Particular to this re-analysis of incidents, and in relation to this research, was the identification of any human performance related errors which may be attributable to the individual working with others; other controllers on the same sector, controllers in other sectors, supervisory relationships and pilot communication and co-operation. However to analyse each incident completely, all aspects of the individual and their operational environment were considered.

The following section explains the methodology used in the analyses.

5.1.1 The conceptual framework

The literature review has derived the following components of a human error conceptual framework:

- A human information processing model – this seems to be the most relevant model of human performance for ATM, as it encompasses all relevant ATM behaviours and also allows a focus on certain ATM-specific aspects such as 'the picture' and situation awareness.

- Error Detail and Error Mechanisms – these appear to be the main structural aspects that enable an analysis of human errors which has been successful in other industries. This would include the following:

  Error / Violation – the external manifestation of the error (omission);

  Error Detail – the internal manifestation of the error within each cognitive domain (late detection);

  Error Mechanisms and Information Processing level– the psychological or internal mechanism of the error within each cognitive domain (perceptual tunnelling)

- Contextual Conditions – a set of ATM contextual conditions are included within the framework. These are grouped into three categories; individual/team issues, task/environmental issues and organisational/systemic issues.

5.1.2 Principle of the classification system

The basic principle of the classification system which is modelled from the enhanced human information processing model (figure 3.1) is illustrated in the following tables and figures.

Firstly the Error or Violation is identified and is known as the Error Type. The classification system then defines four Error Detail levels and for each is listed the corresponding Error Mechanism and Information Processing levels for which it is associated. These associations are summarised in the following Table .

Table 5.1.1 . Relation between Error Detail, Error Mechanism and Information Processing level.

Error Detail	Cognitive Function	Error Mechanism	Information Processing level
Perception and Vigilance	Detection Identification Comparison	Hearback error Mishear Late auditory recognition No/late detection (visual) No identification Misidentification Misread	Visual search failure Monitoring failure Psychological bias Information overload/confusion Discrimination problem Stimulus overload Distraction/ Preoccupation Vigilance problems
Memory	Recall perceptual information	Forget to monitor Forget temporary information	Equipment mode error Similarity interference Memory capacity overload
working memory	Previous actions Immediate/ current action Prospective memory	Forget previous actions Prospective memory failure Inaccurate or no recall of temporary information	Distraction Preoccupation
long-term memory	Stored information- procedural and declarative knowledge	Misrecall/ no recall of information	Negative transfer of information Mis-stored information Insufficient learning Rarely used information
Planning and Decision Making	Judgement Planning Decision Making	Misjudgement Incorrect decision or plan No decision or plan Late decision or plan Under plan	Incorrect/lack knowledge Failure to consider side effects Integration failure Misunderstanding Cognitive fixation Incorrect assumption Risk recognition failure
Response Execution	Timing Positioning Selection Writing Communicating	Selection/positioning/ timing error Information not transmitted Unclear/ incorrect information transmitted Omission	Spatial confusion Misarticulation Thought/habit intrusion Environmental intrusion/distraction Slip of the tongue/pen Similar look/function

The Error Mechanism describes the internal manifestation of an error, hence the failure of a cognitive function within this area. The role of the Error Mechanism in this classification system is to provide an interface between the Error Detail and the Information Processing level affected. The Information Processing levels in turn describe how psychological causes influence the Error Mechanism within each Error Detail. This can be graphically illustrated in the following Figure.

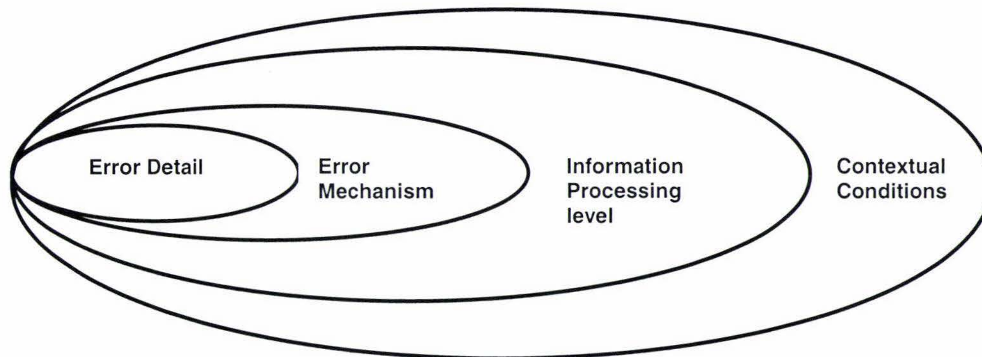


Figure 5.1.1 Spheres of influence of Error Detail, Error Mechanism, Information Processing levels and Contextual Conditions

The final method proved to be efficient in terms of data gathering, since only a few of the analysable events lacked data. Sufficient data was also gathered with the observation methods to apply the error technique to the errors and violations observed. The method also highlighted valuable information about how air traffic controllers actually work, how they use expert judgement to deviate from planned or prescribed practice within the system margins and manage safety.

5.1.3 Extending the classification to include teamwork

A realistic approach to the ATM environment must also acknowledge that controllers work as a team and in teams. It is therefore necessary that the classification system and the underlying framework is capable of representing team factors and functions. These issues are found in the Contextual Conditions and include the following eighteen situations:

- Poor/unclear handover/takeover
- Poor/unclear co-ordination
- Poor communication – pilot and colleagues
- Poor team relations – personality, conflict, pairing
- Returning to sector after a break
- Temporary un-manned position
- New/temporary team allocation
- Poor/unclear working methods, responsibilities
- Trust in others – over/under/mis
- Inadequate assertiveness
- Team pressure
- Cultural pressure
- Duty of care
- Supervisory problems
- Poor/inadequate support from flight-data
- Poor/ inadequate support from maintenance
- High administrative workload
- Other team and social problems

The full explanation of the error analysis technique can be found in Appendix B.

Despite the difficulties of re-analysing ATM incidents, 77 incidents were used for this activity. The following table summarises this incident report data.

Table 5.1.2 Summary of ATM incident cases

Country	Number of Incidents	Average Number of Errors per Incident
Australasia	15	2.8
European UAC	5	1.3
Finland	1	3.0
Netherlands	1	5.0
Sweden	20	2.4*
United Kingdom	30	2.4*
United States	5	1.4*
TOTAL	**77**	**2.6**

* includes known violations

At least two experts (human factors specialist/psychologist/ATM incident investigator) analysed each incident to allow not only the reliability of opinion, but also allowed a

measure of validity. [A separate research programme has subsequently supported the inter-rater reliability of this technique – EATMP, 2002c]

The following results indicate the details of the incidents.
Firstly the Error or Violation type was identified, this represents the observed activity within the occurrence.

Table 5.1.3 Identification of error or violation types within ATM occurrences

Error/Violation types	Countries*			
	USA & Australasia	UK	Europe	TOTAL
Timing of Action				**19**
Action too early/late	4	9	6	19
Selection of Action				**152**
Omission	13	40	32	85
Action too much/little	1	2		3
Wrong action on right object	17	26	16	59
Right action on wrong object	3		1	4
Wrong action on wrong object			1	1
Information Transmission				**86**
Unclear information transmitted/sent		4	5	9
Information not received/obtained		9	1	10
Information not transmitted/sent	3	16	1	20
Information not written/typed		2		2
Incomplete information transmitted/sent		1	26	27
Incomplete information written/typed			2	2
Incorrect information transmitted/sent		3	8	11
Incorrect information written/typed		4	1	5
Violation				**21**
Situational violation	3	7	6	16
Exceptional violation			2	2
General violation		3		3
TOTAL	**44**	**126**	**108**	**278**

* for simplicity results were grouped into three main country areas; USA and Australasia, UK and Europe

Results indicated that there were 257 errors and 21 violations. The most reported error/violation types were found in the areas of omission and situational violation. Most error types appear in the selection of action – 152 errors, (54%) and the next most reported area is associated with information transfer – 86 errors (39%), 27 or 9% being concerned with incomplete information transmitted or sent. The large amount of situation violations concurs with other research in process control, and other transport systems. Situation violation indicates that the operator, although knowing they were breaking a rule or procedure, believe they are safe in doing so as this activity has not caused a previous problem. It is interesting that each country group has a similar profile, that is, the same types of errors were found in similar percentages, despite the possible bias in both the country of origin and investigation analyst.

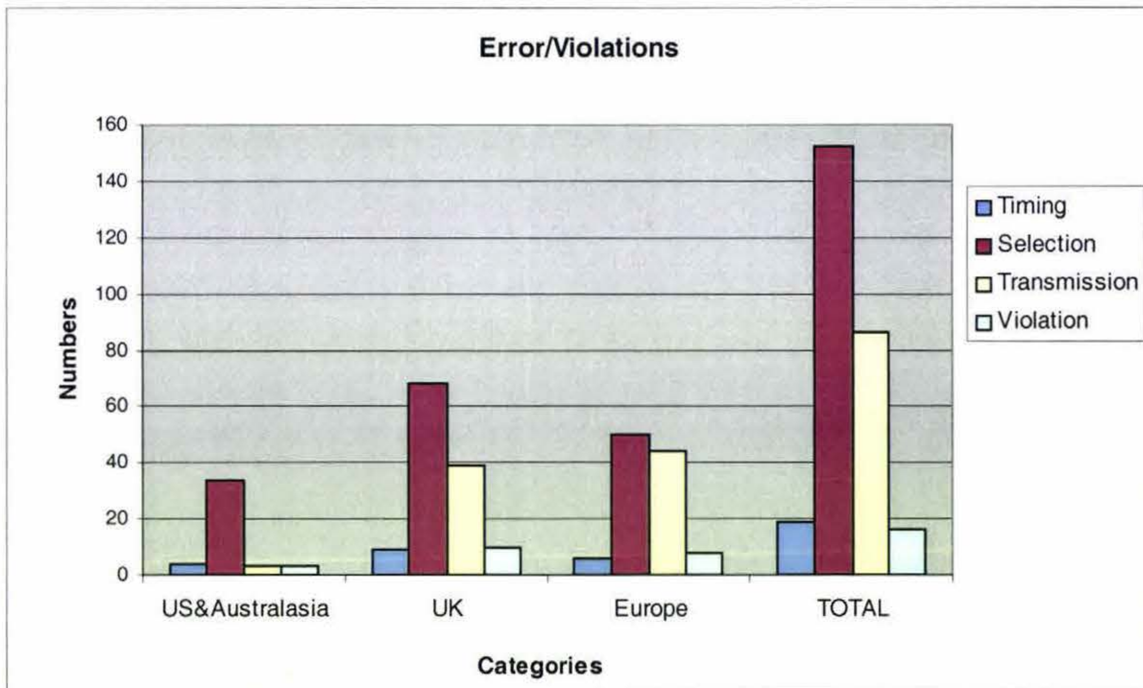


Figure 5.1.2. The distribution of error/violation types

Once the error/violation types could be identified, the analysts then had to ascertain which error mechanism was responsible for the error.

Table 5.1.4. Identification of the error mechanism within the error type

Error Mechanism	Countries			
	USA & Australasia	UK	Europe	**TOTAL**
Perception and Vigilance				**52**
Hearback error	1	8	5	14
Mishear	3	3	1	7
Late auditory recognition		1		1
No detection (visual)	5	10	2	17
Late detection (visual)		5	3	8
No identification		3		3
Misidentification		1		1
Misread		1		1
Working Memory				**15**
Forget to monitor			1	1
Forget to perform action	1			1
Forget planned action		4	1	5
Forget previous action		2		2
Forget temporary information	1	2		3
Inaccurate recall of temporary information	1	1	1	3
Long Term Memory				**1**
No recall of temporary information	1			1
Planning and Decision Making				**119**
Misprojection of a/c	11	4	7	22
Incorrect decision or plan	17	32	25	74
No decision or plan		14	7	21
Late decision or plan	1			1
Insufficient plan			1	1
Response Execution				**11**
Selection error	2		1	3
Information not transmitted		1		1
Unclear information transmitted		1		1
Incorrect information transmitted		4	1	5
Omission			1	1
TOTAL	**44**	**97**	**57**	**198**

In terms of the Error Mechanisms, the highest number are found in Planning and Decision making – 119 errors (60%), more precisely the problems lie in the area of

incorrect decision or plan. The second highest area of concern can be seen in Perception and Vigilance – 52 errors (26%), and more precisely in the problems of hearback. Again the errors in each category are similarly reflected in all country groups, showing comparable trends.

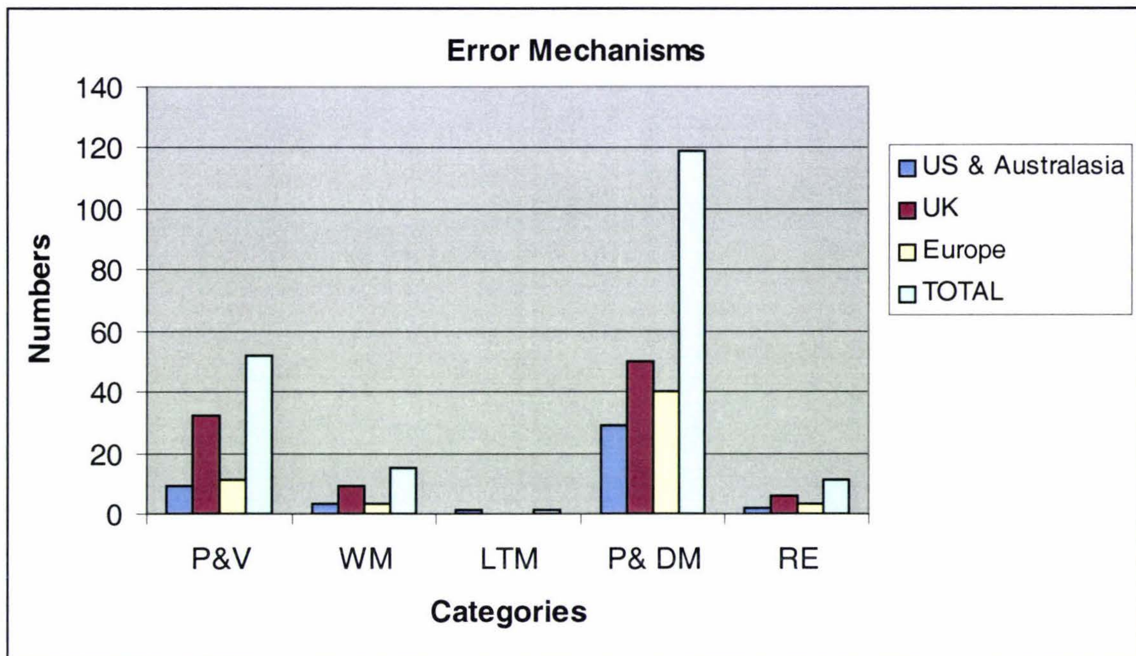


Figure 5.1.3. The distribution of error mechanisms

The most specific analysis is found in the next stage of analysis in which the identification of the failed information processing level is identified.

Table 5.1.5. Identification of the information processing failures within the error

Information Processing Level	Countries			
	USA & Australasia	UK	Europe	**TOTAL**
Perception and Vigilance				**45**
Visual search failure	3	2	1	6
Monitoring failure	1	9		10
Expectation bias	5	6	8	19
Spatial confusion		1	1	2
Information overload		4		4
Distraction		3		3
Preoccupation		1		1

Working Memory				**10**
Memory capacity overload	2			2
Similarity of information	1	1	2	4
Distraction		2	2	4
Planning and Decision Making				**106**
Incorrect knowledge	2	6		8
Lack of knowledge	6	6		12
Integration failure	12	2	5	19
Failure to consider side effects	6	10	4	20
Fixation		3		3
Incorrect assumption	4	17	15	36
Prioritisation error	1			1
Risk recognition failure	2	5		7
Response Execution				**12**
Spatial confusion	2		1	3
Unclear speech		1		1
Intrusion of thoughts		3	1	4
Environmental intrusion/distraction		1		1
Slip of the tongue/pen	3			3
TOTAL	**50**	**83**	**40**	**173**

The Information Processing levels, perhaps not surprisingly indicate the previous high involvement of Planning and Decision Making – 106 error categories (61%) and Perception and Vigilance – 45 errors categories (26%) respectively. The specific areas of concern are incorrect assumption, failure to consider side effects and integration failure in planning and decision making and expectation and monitoring failure in the category of perception and vigilance.

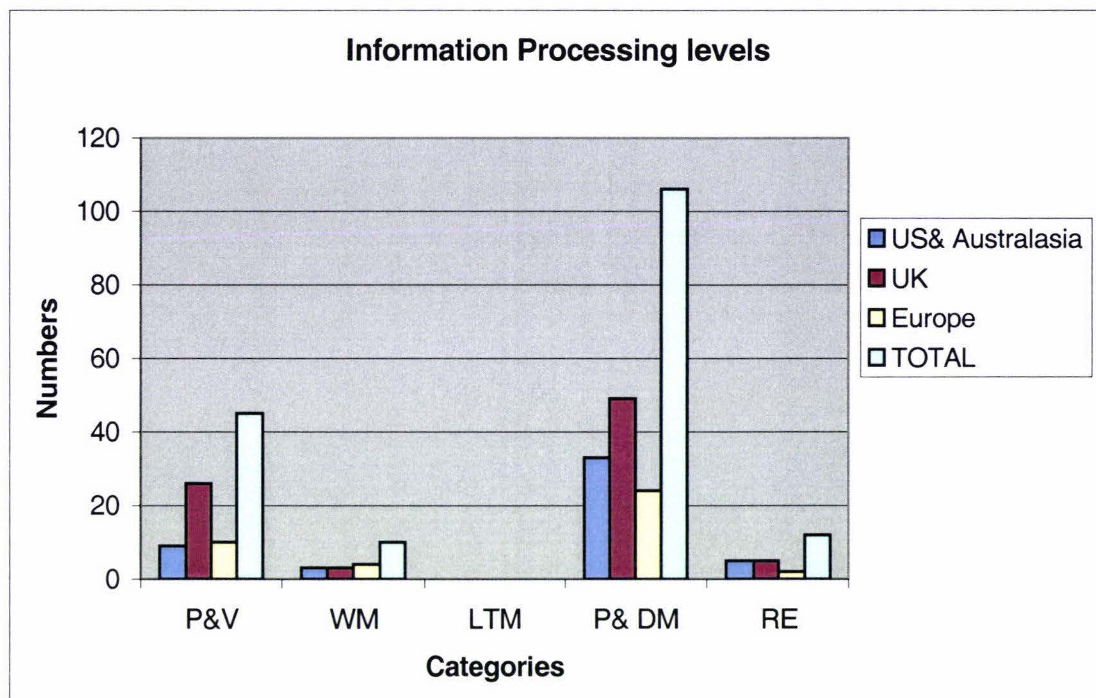


Figure 5.1.4. The distribution of information processing levels

Lastly the areas most concerned in relation to the context in which the errors were committed were examined.

Table 5.1.6. Identification of the contextual conditions surrounding the errors

Contextual Conditions	Countries			
	USA and Australasia	UK	Europe	**TOTAL**
Traffic and Airspace	18	36	10	**64**
Pilot Actions		3		**3**
Weather	3	1	2	**6**
Pilot-ATCO communication		4		**4**
Workplace design and HMI/equipment factors	20	16	7	**43**
Procedures and Documentation	11	11	16	**38**
Training and Experience	17	8	4	**29**
Environment	10	5	9	**24**
Personal Factors	4	1	4	**9**
Team Factors	21	30	16	**67**
Organisational Factors	6	2	5	**13**
TOTAL	**110**	**117**	**73**	**300**

Finally the Contextual Conditions identified in the incidents again indicated similar trends across country groups. The main problems can be found in Team factors – 67 events (27%), Traffic and Airspace – 64 events (21%), Workplace design / HMI – 43 events (14%) and Procedures and Documentation – 38 events (12%).

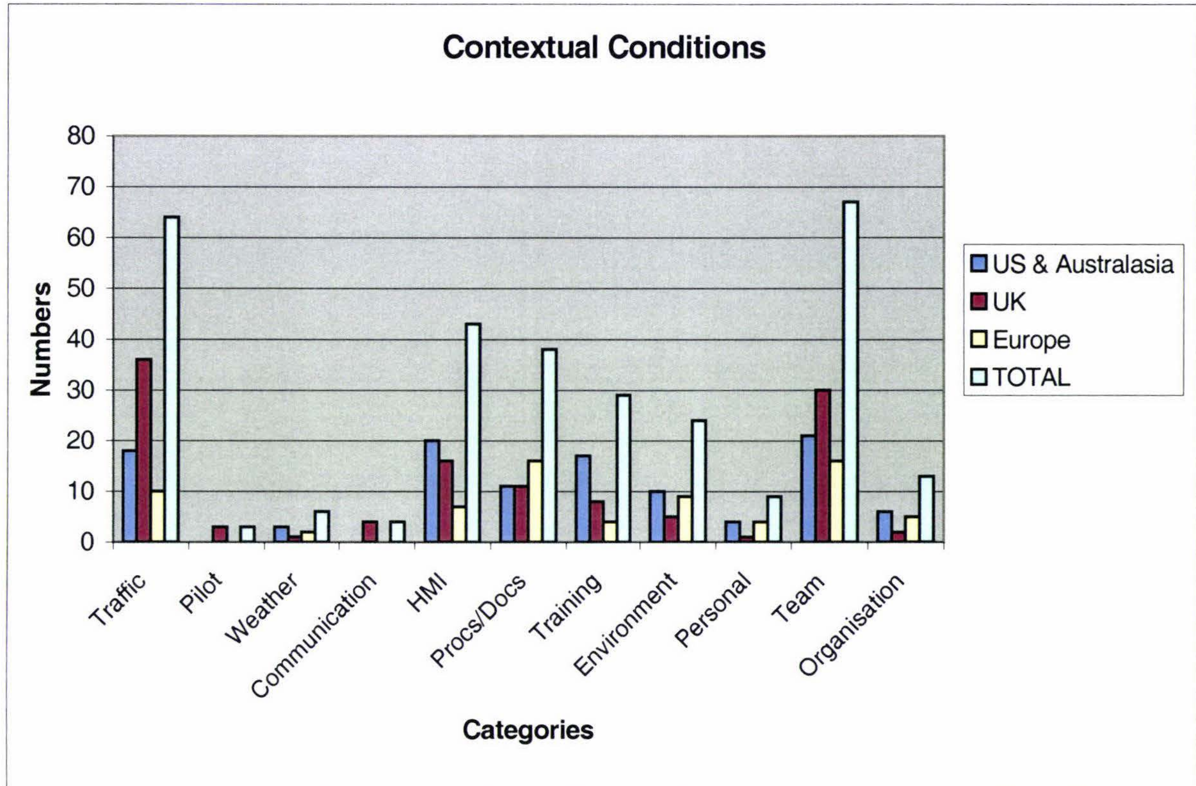


Figure 5.1.5: The distribution of contextual conditions

When analysing these issues more closely the following information helps to clarify the main categories. Within the Team factors, the problems of co-ordination with other sectors or centres is the most frequent, as well as misunderstanding between the radar/tower and planner/ground controllers. This category also includes the issues of poor or inadequate supervision and on the job training issues. The typical Traffic and Airspace problems arise from high numbers of aircraft, the complexity of aircraft movement (ascending, descending and crossing traffic) and non-standard flight requests. Workplace design and HMI errors were mostly associated with action slips and lapses with the use of new systems or equipment which were difficult to understand or were not intuitive to use.

Although a great step forward in the identification of errors within this domain, the results do not illustrate the interdependencies of the team members in a sequential

fashion. It was realised from the results so far that there were certain categories of errors which were more common, but the method failed to detail in which way the members of the team could recognise, detect and help recover these errors. It was therefore thought that the development of a methodology which allowed an analysis of the joint contribution of the personnel within the dynamic of the team, that is when and where the controllers and pilots interacted, would be beneficial.

Five incidents from the original pool of 77 were chosen as candidates for this development. The final methodology, which was accepted by several incident investigators, is known as JEDI – the **J**oint **E**rror **D**evelopment of **I**ncidents and the following figure illustrates the method with the use of one of the original occurrences from this study.

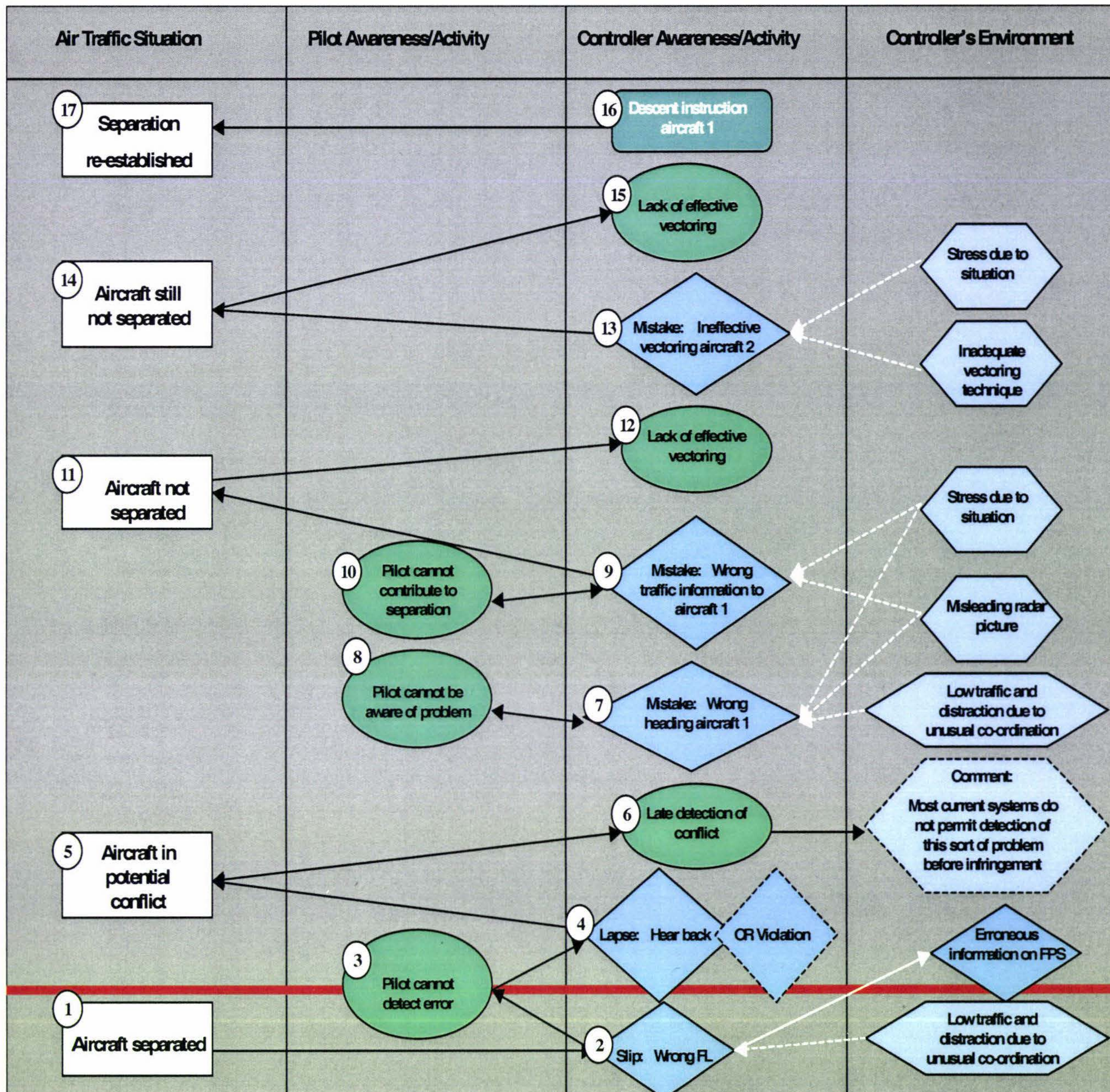
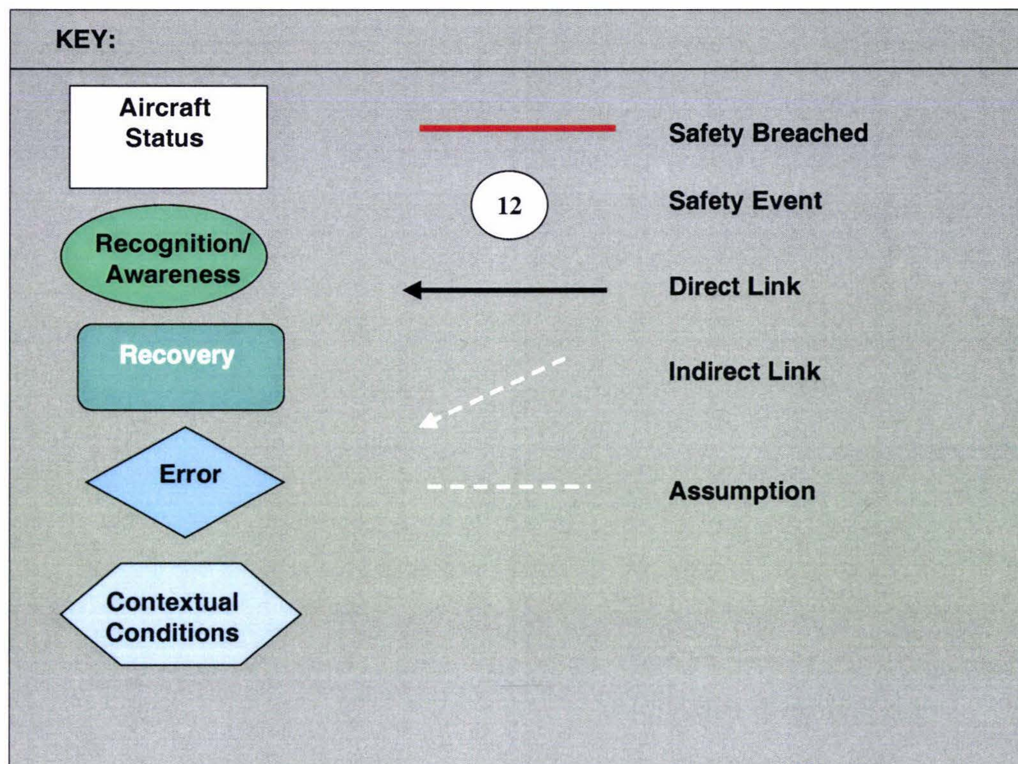


Figure 5.1.6 Joint Error Development of Incidents – JEDI

Table 5.1.7 Key to the Joint Error Development of Incidents - JEDI



The JEDI methodology allowed for the first time an explanation of the dependencies found in team error, particularly in terms of the chronology of an incident. This methodology also illustrated where the most critical recognition, detection and recovery stages appeared and which member of the team was responsible for each.

The example given illustrates that there were 17 safety events or steps in this incident in which three members of the team generated the risky situation. Firstly a co-ordination problem led to the first error at event 2. This was followed by several errors by the controller (events 4,6,7,9) in which the pilot had no influence. Finally the controller again made several errors (events 12,13,15) until at event 16 the controller was able to recognise the error and recover the situation with a pilot instruction. The method also indicated the inability of any of the team members to recognise the situation and how the controller's environment played an increasingly deteriorating role in the severity of the situation.

5.1.4 Findings and implications

Findings from this part of the research indicated that despite the possibility of variations between and within incident reports there seemed to be some consistency across different country cultures and expertise. As no previous work similar to this had been reported in the ATM system, it was difficult to predict which areas of cognitive failure and context would be found to be the most problematic. This part of the study indicated that it was the planning and decision making issues and in particular incomplete decision or plan, which were caused by incorrect assumptions that caused the most frequent errors. These errors were heavily influenced negatively by poor or inadequate team work associated with co-ordination and communication within and between sectors and units. These final problems were compounded by the high levels and complexity of the traffic to be co-ordinated between sectors and centres.

Finally a new methodology to try and recognise these team dependency problems was developed and this method, known as JEDI, successfully illustrated how the team members were able to recognise and manage the risk.

From the results of the first study it was recognised that the air traffic control team has a great influence on the vulnerability of the individuals within the sub-team groupings. It was not predicted that team issues would be quite so prominent in the errors and error chains leading to occurrences. However as a result of this influence, the second part of this research took on more significance, and it was thought very important to try and capture air traffic controllers attitudes relating to team work and its impact on safety.

5.2 Study 2 – Teamwork and safety in air traffic management

The area of Crew Resource Management (CRM) has dominated research in aviation teamwork and safety. The roots of CRM can be traced back to the early 1980s when research into the causes of air transport accidents indicated the failures of inter-personal communications, decision making and leadership (Cooper, White and Lauber, 1980). Crew Resource Management was applied to the process of training crews to reduce 'pilot error' by encouraging a better use of the human resources on the flight-deck. Since this time, CRM has undergone many changes (Helmreich, Merritt and Wilhelm, 1999) and has now been incorporated into other domains such as air traffic control, medicine and the shipping industry.

For this part of the work a small group of air traffic controllers was asked about their perception with regard to safety and the team work within their working environment. The development of the Air Traffic Control Team Safety Questionnaire (ATCTSQ) was based on the work undertaken in flight crew resource management (FMAQ, Helmreich, Merritt, Sherman, Gregovich and Weiner, 1993) and operation room management (ORMAQ, Helmreich, Schaefer, Hines and Sexton, 1996).
A matrix of six issues within the Team Safety areas were identified as the basis of questions to be evaluated with the ATCTSQ. These can be seen in the following figure.

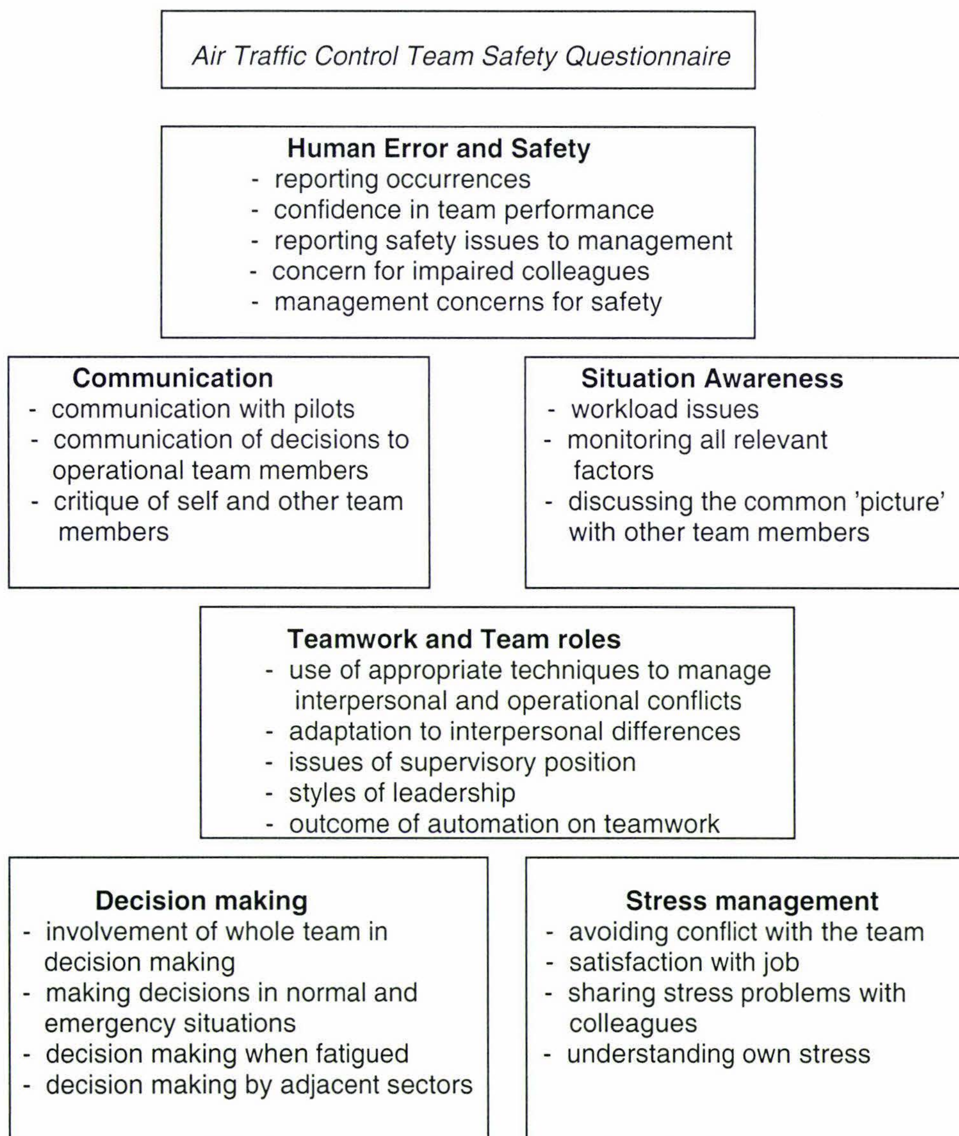


Figure 5.2.1. Basic concepts found in the Air Traffic Control Team Safety Questionnaire

The complete questionnaire can be found in Appendix B.

The questionnaire itself was designed in three main sections.

Section one asked a number of questions regarding the perceived satisfaction of basic skills, handling of normal and emergency traffic, training instruction, shift arrangements, leave and quality of manuals. The responses were given on a five point scale (A-E) from Very Unsatisfactory to Very Satisfactory.

Section two contained all those questions associated with attitudes and behaviours towards the controller and their team work which were summarised in figure 5.2.1. The questions in this section were designed to ascertain the attitudes of the controllers towards various safety issues as they affected themselves and the team. The six individual areas associated with safety and the team were randomly allocated and balanced throughout the questionnaire.

As with previous questionnaires of the same nature the responses in this section were on a five point scale (1- 5) from Strongly Agree to Strongly Disagree.

Section three covered questions regarding demographic data such as; gender, years of service, years in functional positions, and present position.

5.2.1 Stability and reliability

The ATCTSQ was subject to both test-retest and Cronbach Alpha reliability tests. The test-retest reliability was undertaken with 25 subjects from countries other than those involved in the present research. The test-retest reliabilty was r = .68 which was considered reliable for this type of questionnaire, a subjective, self report format. A 't' test was also performed on this data and revealed no significant differences between the first and second responses. This indicated that the control group did not change their responses demonstrating the stability of this questionnaire. The reliability of the questionnaire items were subject to a Cronbach Alpha test with all 140 subjects[5] from within Europe. The result for this reliability was r = .71, which was highly reliable considering the nature of the questionnaire.

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[5] It should be noted that although the total number of cases in this evaluation was 140, in some analyses only some of these cases could be considered because of subjects who did not respond to all questions.

5.2.2 Demographic statistics

The following table details the overall breakdown concerning factors such as gender, average years in ATC and the average years in each functional position.

Table 5.2.1. Breakdown of demographic data

Gender	**Number**
Male	120
Female	16
No response	4
Total	**140**
Years in ATC	**Average Number**
Tower	12.9
Area	12.3
En-route	9.0
Total	16.3

5.2.3 Descriptive statistics

The following results indicate the variables associated with the first section of the questionnaire, those issues regarding the perceived satisfaction of basic skill, handling of normal and emergency situations, training, instruction, shift arrangements, leave and the quality of manuals in the operational units from all test sites.

Table 5.2.2 : Responses regarding section 1 of the ATCTSQ

Questions	Responses
Q1 - Your own basic ATC training	With regard to their own basic ATC training the majority of responses indicated a satisfactory (38%) or very satisfactory (11%) response.
Q2 - Your own basic ATC instructor training	In response to the satisfaction with their own ATC instructor training the majority indicated either satisfactory (38%) or neutral (13%) responses
Q3 - Your own validation or recurrent training	With regard to satisfaction with their own validation or recurrent training responses varied between very satisfactory (7%), satisfactory (28%), neutral (12%), unsatisfactory (13%) and very unsatisfactory (2%).
Q4 - Your own OJT instructor skills	The response to their own on the job training instructor skills were again varied. Twelve percent responded as unsatisfactory, 11% as neutral, although the highest responses came from the categories of satisfactory (28%) and very satisfactory (7%).
Q5 - Simulator training	The majority of responses indicated that attitudes towards simulator training were satisfactory (29%). However 14% felt this training was unsatisfactory and 11% indicated a neutral response.
Q6 - Operations Manuals	Approximately 23% responded that they were satisfied with the quality of operations manuals and 7% felt very satisfied. Fifteen percent considered these were unsatisfactory and 2% felt they were very unsatisfactory. Thirteen percent indicated a neutral response.
Q7 - Safety Manuals	There was rather a mixed response with regard to the quality of safety manuals. The majority felt these were unsatisfactory 20.5%, although 17% found them satisfactory. Nearly 15% gave a neutral response.
Q8 - Shift cycle	The majority of responses with regard to shift cycles were satisfactory (24%) or very satisfactory (13%). Nine per cent indicated a neutral response.
Q9 - Shift schedule	A similar pattern with regard to shift schedules indicated the majority were satisfied (23%) or very satisfied (16%) with their present arrangements.
Q10 - Length of leave	Again the majority (23%) indicated they were satisfied or very satisfied (9%) with their length of leave. However 13% indicated a neutral response to this question.

Questions	Responses
Q11 - My skills in handling normal operations	Twenty seven per cent of those who responded considered that their skills with handling normal traffic was satisfactory or very satisfactory (21%).
Q12 - My skills in handling emergencies	Responses to skills in handling emergency traffic was a little more varied. Twenty eight per cent considered their skills were satisfactory, whilst 7% felt they were very satisfactory. Seven per cent felt they were unsatisfactory and 17% indicated a neutral response.
Q13 - Feedback on my daily operational performance	Thirty percent of those who responded felt that feedback on their daily operational performance was satisfactory and 7% felt it was unsatisfactory. Five per cent felt that it was very satisfactory whilst 2% felt it was very unsatisfactory. Sixteen per cent indicated a neutral response.

These responses indicate generally a high level of satisfaction for issues involving training, although there was some concern shown in OJTI and simulator issues. These typically are team role related issues. Shift cycles, shift schedules and length of leave were considered satisfactory. Concerns were shown, however, for the status of the operation and safety manuals and the issues concerned with handling emergency traffic and feedback in the operational environment, which is of direct concern within team safety in this environment. The following section describes the results from the specific questions regarding the team and safety.

5.2.4 Results from the team and safety questions

The following figure indicates the average response of the subjects to all 22 questions.

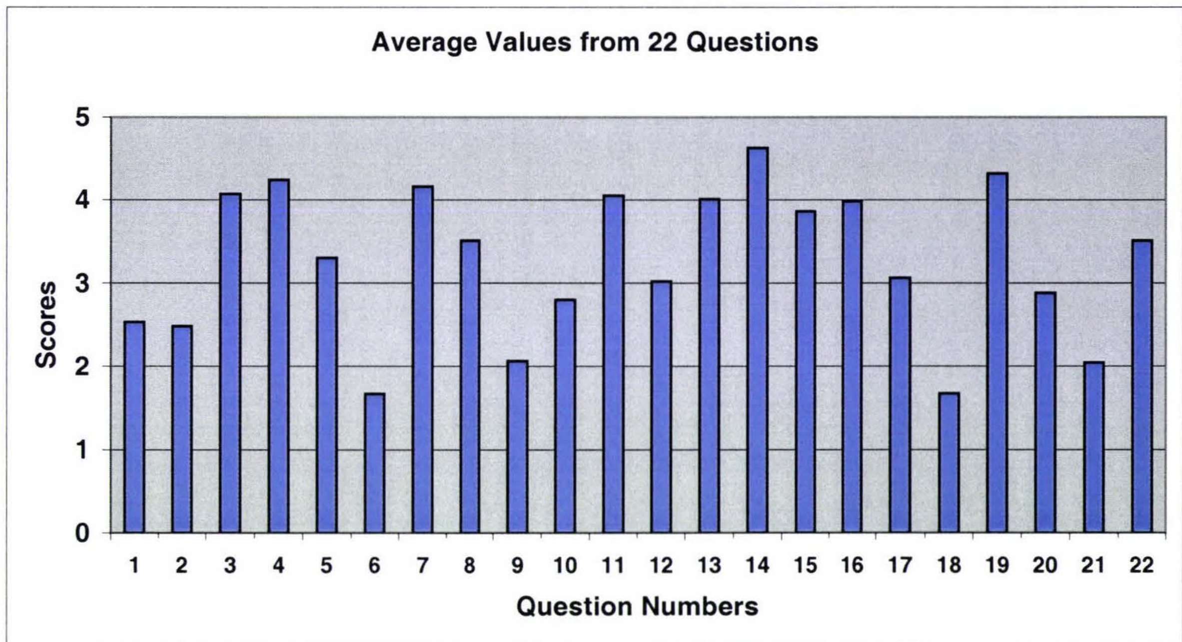

Figure 5.2.2 : Graph indicating the results of the Team Safety Questionnaire

The question responses ranged on a five point scale from 1- strongly agree to 5- strongly disagree. The following table details each response to the team safety questions.

Table 5.2.3 : Responses regarding section 2 of the ATCTSQ

Questions	Responses
Q1. Automation reduces the requirement for team members to monitor the traffic situation closely.	The average response was 2.5, which indicated that controllers slightly disagreed or were neutral about this statement. In other words they felt, although not strongly, that automation will not reduce the requirement for the team members to monitor the traffic.
Q2. It is not my place to give pilots advice, other than airways information and clearance details.	The average response was 2.4, which suggested the controllers also slightly disagreed with this statement, that is they believed they should give pilots information and advice about issues other than airways information.
Q3. Team members share responsibility for prioritising activities in high workload situations.	The average response was 4.0, which indicated that the controllers slightly agreed with this statement, although not very strongly.

Questions	Responses
Q4. Effective team co-ordination requires controllers to take into account the personalities of other controllers.	The average result was 4.2, indicating the controllers agreed with this statement.
Q5. It is easier to make decisions when you first take over on an operating position.	The average response was 3.3, indicating that the controllers felt neutral about this statement.
Q6. Asking for assistance makes one appear incompetent.	The average response was1.6, which suggested the controllers disagreed with this statement.
Q7. To resolve conflicts, controllers should openly discuss their strategies with each other.	The average response for this item was 4.2, which indicated that the controllers slightly agreed with this statement.
Q8. It is easier to communicate with my own team than other teams and units.	The average result 3.5, indicating that the controllers felt neutral about this statement, which has implications for team working in co-ordination.
Q9. Trainees should not question senior team members' decisions.	A response of 2.1, indicated that the controllers slightly disagreed with this statement, and therefore considered trainees part of the co-operative team, although not strongly.
Q10. Flight crews never demand too much.	A response of 2.8, indicated that the controllers slightly disagreed with this statement.
Q11. Casual, social conversation in the operating environment during periods of low workload can improve team cohesion.	A response of 4.1, indicated that the controllers agreed with this statement.
Q12. It is important to avoid negative comments about the procedures and techniques of other controllers.	An average result of 3.0, indicated that the controllers felt neutral about this statement, which may have an effect on team working practices.
Q13. Discussing the traffic picture with other controllers helps to keep your own picture clearer.	An average result of 4.0, suggested the controllers slightly agreed with this statement, which may have an effect on activities when working with new technologies.
Q14. Good communication is as important as technical proficiency in the controlling environment.	An average result of 4.6, suggested the controllers strongly agreed with this statement.

Questions	Responses
Q15. My unit would be capable of handling the situation if there was a system breakdown.	A response of 3.9, indicated that the controllers slightly agreed with this statement. This will have major implications in new technology environments.
Q16. I should maintain the traffic picture of the controllers I work with.	A response of 4.0, indicated that the controllers agreed with this statement.
Q17. Our training has prepared us to work as a well co-ordinated team in an emergency.	The average response from this item of 3.1, indicated that the controllers felt neutral about this statement, which has serious safety implications.
Q18. Supervisors who encourage suggestions from team members are ineffective.	The average response from this item of 1.6, indicated that the controllers disagreed with this statement.
Q19. I should inform those controllers who are affected by my plans and control actions and ask for their acknowledgement.	The average response from this item of 4.3, indicated that the controllers agreed with this statement.
Q20. Increased automation reduces the need for team communication.	An average response of 2.9 suggested the controllers slightly disagreed with this statement.
Q21. It is better to agree with other team members than to voice a different opinion.	An average response of 2.0 indicated the controllers slightly disagreed with this statement, although not strongly.
Q22. I perform as well with other units as with my own.	The average response from this item of 3.5 indicated that the controllers slightly agreed with this statement. This suggested that they believe their work with their own unit is as good as with other units.

5.2.5 Findings and implications

Generally the responses to the questions indicate that the controllers felt that they displayed professional and competent working practices within and between the units they worked, although few of the responses had a strong negative (disagree) or positive (agree) dimension. They had neutral feelings with regard to many communication issues, particularly with other colleagues and pilots. They also felt neutral about handling an emergency by the team, which may indicate a safety problem. The controllers generally felt issues about team communication and conflict was important and reported that communication intention was the most important issue to share with others. The controllers tended to agree, slightly, that questioning

when uncertain was acceptable, which was a positive team attitude. Possibly the most interesting responses were concerned with system breakdown and emergencies, in which the controllers believed, not only were they not confident in their own abilities, but they had neutral feelings or only slight agreement with reference to the team in an emergency situation and system breakdown respectively.

Although only a small self report survey, the results of the questionnaire has demonstrated some of the safety critical attitudes which are held by controllers and illustrated that their concerns, both positive and negative, can have an impact on team performance.

These results led to a more thorough investigation of the issues demonstrated in both the incident reports and the safety questionnaire responses particularly those which implicate the team in the ATM operational environment.

5.3 Study 3 – Observation of team error in simulation

In the aviation literature there are some examples of successful team behaviours (Cannon-Bowers and Salas, 1990; Orasanu, 1990; Serfaty et al, 1985,1993), but few references are made with regard to errors which are made and generated in this environment. There is some evidence, however, (the Vincennes incident) which indicates that under stress, which reduces an individual's or team's flexibility, more errors are caused. Janis and Mann (1977) stated that under stress, particularly high stress, team members may experience such a reduction in attentional capacity that their normal thought processes are disrupted. It is also known that not all teams appear to be equally affected. Serfaty, Entin and Deckert, (1993) reported that when increasing uncertainty, the team did not increase their error rate, but simply increased their information seeking. Another striking feature of this research was that, from observation, the teams were able to maintain the same level of performance with one third of the time available to make decisions. Serfety, Entin and Deckert (1993) explained that the primary adaptation mechanism that allowed these teams to maintain their performance under high time pressure was a switch from explicit to implicit co-ordination and communication.

There is, however, little or no empirical evidence for these behaviours within the air traffic control environment, but observation and informal discussion would reinforce these findings. It is therefore an important aspect of this research to investigate how

teams, and individuals within those teams, adapt to the changing dynamics within ATM in order to successfully carry out error free performance, or at least performance which does not jeopardise the safety of the system.

In order to tackle this aspect of the research several activities were undertaken. Firstly a simulation session was used to ascertain the dynamics involved in gathering individual and team error data in the operational environment. Secondly, observations were undertaken in a second simulation session to ascertain exactly what the controllers did in a dynamic way to recognise, prevent and recover from errors.
The rationale behind using these experimental protocols was that it was hypothesised that the greatest number of team errors would be created in co-ordination and communication activities. If this was indeed the case, it would hopefully allow for a more precise and objective recording of these issues.

5.3.1 Errors in air traffic management

Evaluations of the error-rate of air traffic controllers under normal operational conditions have never been published, although data from a large European country indicates an average of a hundred serious safety events per year in Air Traffic Control. After closer examination only about ten of these hundred events effectively called for national safety actions, and only one accident was partially attributed to the air traffic control system in the past five years. However these data are only the 'tip of the iceberg' of real error occurrences. Finding out the true error rate in normal operations and understanding the nature of the connection between error occurrence and those errors with negative consequences illustrates a real conceptual challenge.

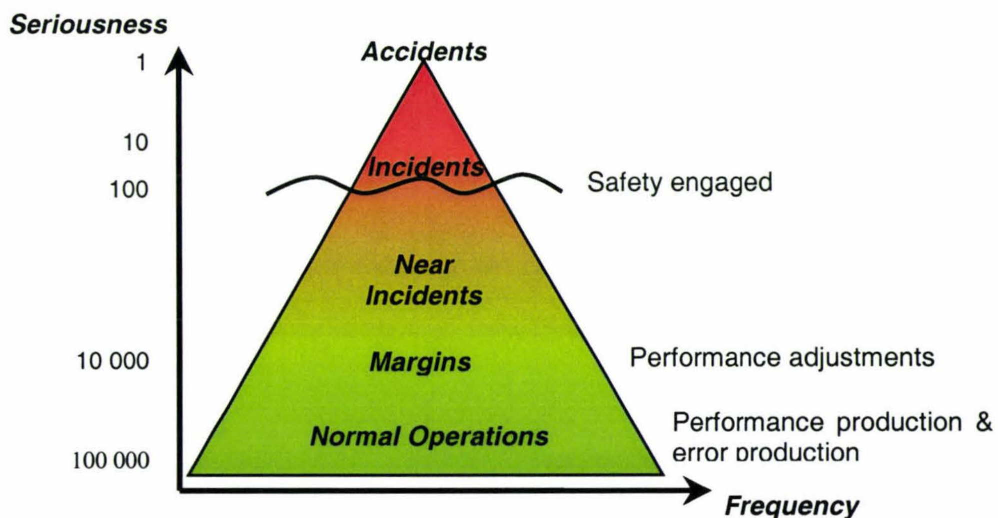

Figure 5.3.1 The relationship between seriousness and frequency

It is therefore reasonable to assume that it takes about a thousand occurrences for an error to emerge that would have adverse consequences and it is only when the error is committed in a specific context that the risk can be ascertained.

5.3.2 Observing errors in the air traffic management environment

There are several problems with regard to the observation of error in the operational environment which probably accounts for almost no research data being gathered in the ATM environment. The problems are fourfold.

Firstly, the result of observation depends on the definition of error given to the observer. The definition used in this work is based on the error outcome and focuses the observation on an action or inaction. However this definition has problems if the observers are not in a position to discuss the error events with the controller. Difficulties also occur that are related to the evaluation of the negative system effects:

- some negative consequences may occur without being linked to an error;
- many errors tend to be ignored by the observer when they are recovered soon after their production;
- some errors tend to be ignored when there is an uncertain evaluation of their consequence in the long term.

Secondly, direct action errors and violations are much easier to observe than tactical and strategic errors. Expertise of the observer in the domain observed (ATCO expertise in ATM) is necessary to detect strategic errors.

Thirdly, the control of the situation requires the control of errors, but the control of errors is the result of a continuous compromise that emphasises error detection and recovery rather than error avoidance. The pragmatic consequence is that error observation should include error management (recognition, detection and recovery), which adds multiple challenges to the observers activity.

Lastly, the topic of error is extremely sensitive for most professionals. The key to obtaining quality data is to ensure the subjects are confident of the motivation of the observers and that the observations will in no way jeopardise their future work.

5.3.3 Observation of human errors in air traffic control simulation

It was decided to observe two simulation exercises for the reasons given above: firstly it was necessary to pilot the methodology used as this technique had never been reported before in an operational environment. Secondly it was unclear how controllers would deal with the different types of error – action and cognition – in a simulated ATM environment. Finally it was important for this research, given the results in section 5.1, to observe how the two controllers (and pilots) interacted to prevent or manage potential and actual errors.

The first simulation would allow for the techniques to be refined for further observation in the second simulation. The two observation exercises in real-time simulated environments were as follows:

- A simulation associated with Free Routes Airspace at the Eurocontrol Experimental Centre in Brétigny, France during September 2000.
- A simulation which was held in a European simulation centre during May 2001.

The detail of these two simulation exercises is described below.

5.3.4 The first simulation exercise

The first simulation exercise was associated with the Free Routes Air Space Project (FRAP) and organised in September 2000 in the Eurocontrol Experimental Centre at Brétigny, France. The objective of the FRAP simulations was to assess the impact of flights using free route air space on the co-ordination between civil and military air traffic control sectors.

Under Free Route (FR) airspace, aircraft in upper air space would be permitted greater flexibility in flying direct routes (i.e., without reference to the current ATS network) than is currently the case. The Free Route Airspace Concept envisions keeping the current route structure below the Free Route altitude and upon entering Free Route airspace, aircraft would be cleared to fly direct requested routes between Free Route entry and exit points.

Free Routes Airspace exercise and methods

One day of training and familiarisation with the FRAP environment was necessary for the observers to understand the FRAP logic and learn the human-machine interface (HMI) dedicated to the simulations.

The simulation program was organised with a shift of 11 controllers: CAA Belgium (1), CAA Sweden (1), CAA Finland (1), Maastricht (2), Belgian Air Force (4), Netherlands Air Force (2). Ten controllers were working on the simulations at any one time whilst one had a break.

The choice of the three controllers for this research was dictated by the choice of the position to be observed, although all controllers volunteered for this exercise.

The observation protocol that was designed for the first observation exercise was based on the experience gained in error analysis. The method contained two main phases described as follows:

Phase1: Observation

Two positions Radar and Planner Controller (RC and PC) were observed by two observers over three 1 1/2 hour sessions. One observer was an experienced controller (ATCO) and the second was a cognitive psychologist with substantial air traffic control and human factors knowledge (HF). The air traffic control (ATCO) observer was seated beside the radar controller and the human factors (HF) observer was situated behind, but in view of both the radar screen and recording monitor. Both observers could listen to the communications on the frequency between the observed controllers and the pilots.
The observation setting is presented schematically in the following figure.

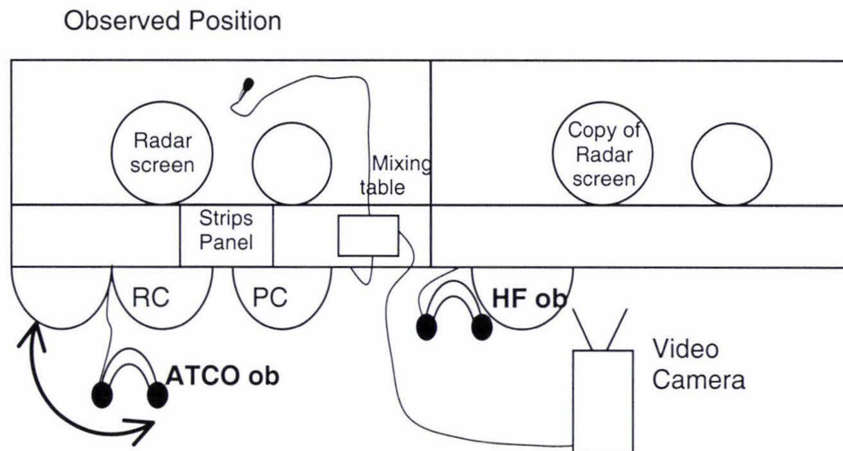

Figure 5.3.2 : The observation setting

Using a commonly understood definition of error and the classifications explained earlier in study 1, the two observers recorded as many errors and detection/recovery strategies as possible by taking free notes on paper, with a time code reference of their observations.

The situation itself was recorded with two video cameras. One camera behind the radar and planning controllers was recording the radar screen whilst another camera from the side was filming the radar controller's profile which included communication with the planning controller.

Phase 2: Debriefing and auto-confrontation interviews

After the simulation session observed, the controllers were interviewed by the two observers, with the support of the video recordings (synchronised on one screen). Auto-confrontation meant that the observed controllers were faced with the video recording of the simulation session and asked to comment freely about what happened. This technique was active since direct questions were asked to the observed controllers in order to gather specific elements of information about the observations made.

Free Routes Airspace results

Results of the observations

Fifty six 'outstanding observations' which could be classified as errors were gathered

over the three observation sessions, using the method described above. These results are summarised in the following table.

Table 5.3.1 Results of the errors observed

Simulation Session	**Total**
S1- En-Route	22
S2- En-Route	18
S3- En-Route	16
Total number of observations	**56**

The observers took note of all issues which they perceived as erroneous events. In many cases these were not only observed errors but included notes relating to their lack of understanding of the situation, deviations from their expectations and deviations from procedures. This resulted in observations that could be classified into three types:

- 'events' that occurred at a specific time (i.e.: 'warning from the adjacent sector');
- 'states' of an aircraft or of a system (i.e.: 'wrong exit level'); related to potential errors and
- 'actions' performed by the controller (i.e.: 'transferring a plane') that were actual errors or potential deviations.

Results of the interviews

All 56 'outstanding observations' were questioned in the three interviews.

The nature of the information collected between the three interviewees was quite variable. The personality of the controller observed greatly influenced the information collected; some controllers were more talkative and co-operative in terms of their openness with respect to errors and their own ways of working. The explanations provided by the observed controllers were also of a different nature, depending on whether they focussed on a precise action error, a specific set of errors or a situational context which was difficult to handle. Typically the interview process was also limited by the complex nature of some of the data or by unexplainable information, particularly concerned with the contextual conditions which had led to the errors.

In spite of these difficulties, the interviews provided a very valuable feedback from the observed controller about what difficulties were encountered, how strategies were

chosen and why certain errors were made. This significantly enriched the understanding of the initial observations.

Results of the error analyses

The analysis technique, discussed in study 1, was used to identify the 56 'outstanding events' observed.

Table 5.3.2 Summary of the error analyses

Error Category	Number Recorded	Prevention[6]	Detection[7]	Recovery[8]	Team Related
Perception & Vigilance					
did not identify	5	Nil	2 PC	2RC	2
did not detect	1	Nil	1PC	Nil	1
hearback	8	Nil	4P	4RC	4
Working Memory					
forget information	3	Nil	2RC	2RC	-
forget planned action	3	Nil	2RC	2RC	-
Long-Term Memory					
recall wrong information	2	Nil	Nil	Nil	-
Judgement,Planning & Decision Making					
incorrect separation	20	Nil	20 CA[9]	11 RC/ 5 PC	- 5
Response Execution					
wrong positioning	1	Nil	Nil	Nil	-
wrong keying	11	Nil	1RC	1RC	-
wrong communication	2	Nil	2 RC	2 RC	-
TOTAL	**56**	**-**	**34**	**29**	**12**

[6] P- Pilot, RC- Radar Controller, PC- Planning Controller
[7] P- Pilot, RC- Radar Controller, PC- Planning Controller
[8] P- Pilot, RC- Radar Controller, PC- Planning Controller
[9] CA - Short Term Conflict Alert

The highest category represented in this analysis was in Judgement, Planning and Decision Making in which there were 20 errors (35%). However this was probably due to the contextual influence of the simulation. The areas of Perception and Vigilance and Response Execution were equally represented with 14 errors (25%) in each category.

Contextual Conditions: the short term conflict alert (STCA) indications (20 errors recorded) may be because the controller either did not believe them or was not sufficiently interested in them because he had already made a plan for separation. The calibration of the STCA may not have been sensitive enough, that is the system may have predicted separation loss which would not eventuate because the controller was or would have separated with firstly a heading change and then a level assignment.

The other high number of errors can be seen in wrong keying, in which most were not detected and recovered. The main reason for this may have been the unfamiliarity with the environment.

It is interesting to note that the pilot and controller (planning and radar) were able to detect and recover many (55 %) of the errors recorded.

It must be said that this simulation was very ambitious in terms of error data gathering. This is because there were many system and procedural issues which were very new to the controllers which inevitably caused rather large artifacts within the type and nature of errors observed and recorded. Some were anomalies regarding the appearance of 'ghost' aircraft on the planning controllers screen, which did not occur on the radar controllers screen. Another problem was the introduction of Short Term Conflict Alert (STCA) in a non standard way (i.e. separation of civilian aircraft was calibrated to 1,000 feet vertically and between civilian and military aircraft it was 2,000 feet vertically). The large number of STCA indications was probably a direct result of this problem.

Generally the results indicated that:

- of the 56 errors recorded about 35% were associated with the technology which was incompatible with the human information processing system (i.e. the controller anticipated before the machine calculated the problem).
- there were approximately five errors identified per hour in this environment which in part may be due to the use of the new technology and procedures.
- the ability for the controllers to prevent any potential errors was not realised on any occasion.

- the task sharing and responsibilities between the radar controller and the planning controller were less structured than anticipated, but in terms of team dynamics 12 events (21%) were successful captured within the team.

The second simulation exercise used the information from the FRAP simulation and attempted to improve, not only the methodology used for error recording with particular emphasis on the team dependencies, but also control for those variables which proved difficult in the FRAP simulation.

5.3.5 The second simulation exercise

The second simulation exercise was related to the testing of changes within airspace sectorisation, in a European country. Three Control Centres were involved in these simulations: two approach control centres and one en-route Control Centre[10].

Airspace Sectorisation exercise and methods

Two days were spent at the simulation centre with the technicians and those responsible for the simulations prior to the observations for familiarisation and training purposes. It was decided to observe two different positions (one approach position and one en-route position), with ATCO observers and human factors specialists (HF) as before.

Three days were spent for the observation sessions themselves: two simulation sessions of about 1 hour each were observed simultaneously on two positions every day with two teams of observers (ATCO and HF). During these sessions approximately six hours of observations were recorded. After each recording session the ATC and HF observers on each position discussed the recorded session and having agreed on the events to be questioned, prepared the interview session. The interviews were then conducted for approximately 1 1/2 hours with the controllers observed.

The controllers involved were both voluntary and experienced. They were all familiar with the simulation environment as well as the sectors on which they were working. Only minor changes to the usual configurations of the sectors were tested at the time, which gave a more reliable and stable simulation platform than the first exercise.

[10] Information regarding the controllers and the operational centres has been requested to remain confidential.

Phase 1: Observation

List of operational observable events. A preliminary list of the operational data observable in ATC was elaborated with the expert ATCO who observed the first simulation exercise. Lists were compiled of actions, events and system states relating to the management of the aircraft from the entry to the exit of the sector. The resulting lists served as a basis to elaborate the instructions for the observers and the questioning technique at interview. The lists took into account the observed performance of the controller and not just those events which are necessarily error-prone.

Observation activities. The observers, who were an ATCO and a human factors specialist, monitored the radar controller (RC) and planner controller (PC) on each position.

Each observation lasted for approximately 1 hour. The observation setting was identical to that in the first exercise simulation (figure 5.3.2). The observers watched and noted the following issues:

- Every action, event or state of the airspace that seemed notable or outstanding such as
    - deviations regarding what could be expected from the situation
    - errors or violations
    - actions which seemed different to expectation
    - activities which were not understood
    - activities which went well

- Every subjective observation on either a tactical or strategic level implemented by the ATCO with regards to safety.

Both observers took notes on all relevant observable events and collected flight progress strips associated with each 'outstanding event'.
Both video recording of the radar screen and audio recordings of the radio telephony and radio were also collected as part of the observation material.

Phase 2: Debriefing

The debriefing was undertaken in a separate area from the operations room and took place immediately after the observation stage. During these sessions, the ATCO and the HF specialist reviewed together all the observations made, using both observation notebooks, the collected flight progress strips and recorded video from the radar screen with all RC/PC/Pilots' communications. They then discussed in detail all observations, reached agreement on the 'outstanding events'. Finally they elaborated the interview questions to be used in the next phase.

Phase 3: Auto-confrontation interviews

The interviews took place in the same room as the debriefing session.
For each hour of observation the interview lasted approximately 1 – 1 1/2 hours. The interviewee was formally asked to agree to the interview and the format of the interview was then explained in detail. All interviewees understood they could withdraw from the process at any time.

Airspace Sectorisation Results

Results of the observations

A total of 101 'outstanding events' were noted before the interview process. During the interview it was established that 15 of the 'outstanding events' could not be classified as errors. The explanation for this will be discussed in the next section referring to the qualitative analysis of this data.

Table 5.3.3 Summary of the initial observed data

Simulation sessions	Total 'outstanding events'
S1- En-Route	13
S1- Approach	26
S2- En-Route	18
S2- Approach	19
S3- En-Route	9
S3- Approach	16
Total	**101**

Results of the interviews

During the interviews it was revealed that when trying to qualify the types of observations made, the errors and violations were not the only 'outstanding events', and that all observations fell in three main categories which could be considered a more quantitative analysis of the data. These three main categories were named:

- Correct Actions - CA
- Expert Judgement Deviations - EJD
- Performance Errors - PE

The following figure summarises these categories and sub-categories as they were derived from the interviews.

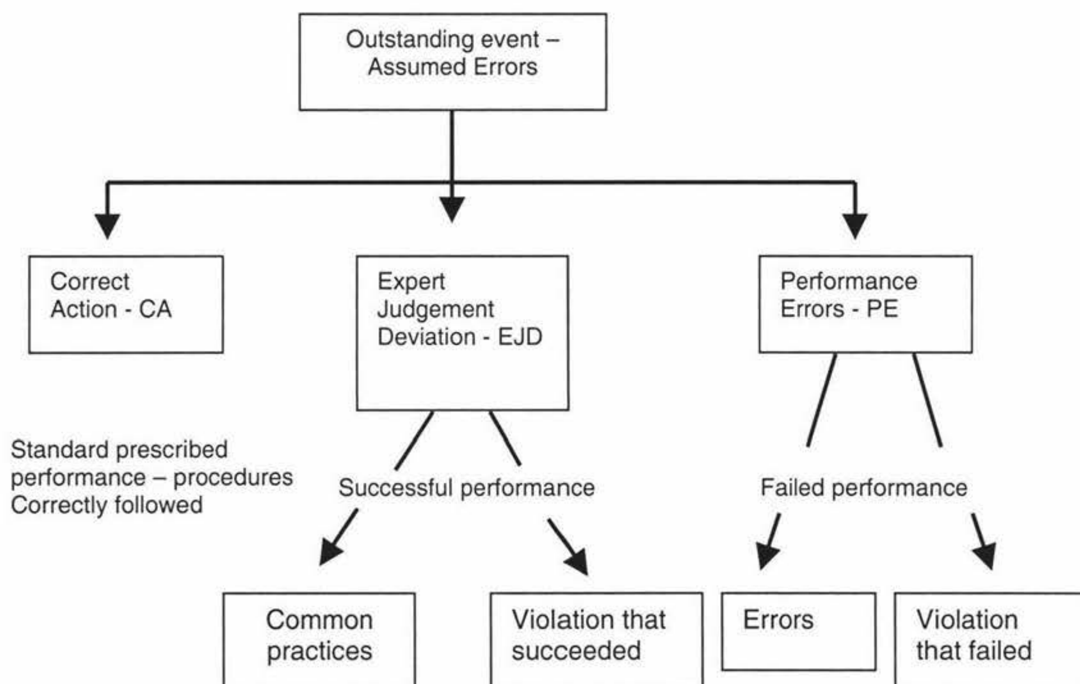

Figure 5.3.3 Categories derived from the observations

An explanation of these categories and examples are described below.

Correct Action - CA:

The action performed by the controller proves to be correct as required by the situation and/or procedures (normal/standard performance). The observer has either misunderstood the situation or was not aware of the procedure to be applied.

Example 1: Correct Action

- Noted by the observer (with regards to the flight strip):
  ' A/C co-ordinated at FL230 and transferred at FL190 '
- At interview: "I cannot give the A/C FL230 because my sector is limited to FL195. Conflicts were solved for this aircraft, so I could transfer it at FL190. *I trust the PC has co-ordinated with the other sector because he has written it on the strip*[11]. I followed the standard procedure: clear the A/C at the highest level in my sector ".

In this case, procedures have been adequately followed, however there may be a risk if inadequate or uncertain procedures are used and there is incomplete co-ordination.

Expert Judgement Deviations - EJD:

In this situation the ATCO acts at the margins of the requirements of the procedures. This includes all the common accepted and personal practices that usually reach a successful performance. They are able to do this because of previous knowledge, skills and experience. Among Expert Judgement Deviations lie clear violations that need to be separated from common accepted and professionally safe practices. Expert Judgement Deviations are goal-oriented (workload management, strategy, task allocation) and may be risky or not risky, depending on the situation or context.

Example 2: Common/preferred practice EJD

- Noted by the observer:
  'Aircraft F-MP is given a heading back to its route late after the conflict resolution, compared to aircraft BZ-JM that is headed back immediately '
- At interview: " I could have given the heading to the F-MP immediately but I preferred waiting 2 minutes to group the two instructions (heading and transfer) in one to save time and avoid over-occupying the frequency (there was a lot of traffic). Moreover, it was not dangerous and *the heading was not problematic for the F-MP regarding its route ".*

[11] All writing in italics indicates those statements which are directly related to team issues

This performance adjustment was aimed at 'saving resources' and managing the high workload. It was not a risky practice, unless the pilot concerned could not or would not comply.

Example 3: Violation EJD

- Noted by the observer:
  'Catch up situation between two aircraft: absence of speed check when one aircraft was transferred '
  The procedure states: assign a speed to the first aircraft and assign a slower speed to the second one.
- At interview: "The two aircraft come from the same level, they are the same types of aircraft, hence they have the same performance. They have the same wind. For me, there is no problem, they've been under control since the integration of their strips. *If I ask for the speed, I loose a lot of time on the frequency*. (the traffic was high and workload also high) I had left aside all that was happening elsewhere ".

This was a Expert Judgement Deviation that can be considered a routine violation, work strategy to save resources and manage workload. Risk was managed, under control but the controller would need to guarantee the aircraft had the same performance.

Example 4: Risky EJD

- Noted by the observer:
  'Conflict between two aircraft: one is going to catch up the other and they are at the same flight level. No instruction is given to manage the conflict (speed allocation) '
- At interview: " I had seen the conflict. But it's the task of the PC to co-ordinate with the next sector to make sure they accepted to take the A/C like that. *There was a lot of traffic so I didn't have time to talk to the PC*. The next sector usually manages this kind of situation (the traffic was high and workload also high)".

This observation can be considered an Expert Judgement Deviation, because the controller was aware of the conflict and was monitoring it. The controller let the PC

make a co-ordination with the next sector. The situation was clearly risky, in the absence of any communication between the two controllers.

Performance Error - PE:

In this situation the controller acts in a similar way to the Expert Judgement Deviation but the outcome is actually or potentially different from the intentions or expectations (failed performance). These are classed as errors (unintentional actions or intentions recognised as inappropriate) or violations. Performance Errors may be risky or not risky, depending on the situation or context.

Example 5: Performance Error

- Noted by the observer:
  'Aircraft transferred to the feeder controller too early'
- At interview: "The transfer was not very good. It would have been better for me to wait 20 seconds more and pass the cross-point before transferring. *This would have avoided the feeder controller wondering whether the conflict was already solved or not.* This overloads them and forces them to accept what I thought was fine "

This was an error (action recognised as inappropriate by the controller). The controller took the risk of overloading the feeder controller, hence the situation was risky.

Example 6:Performance Error

- Noted by the observer:
  'The controller gives an instruction to reduce speed to 250 knots, but the pilot has already announced that he was at 220 knots'
- At interview: " I had forgotten he was already at 220 knots. *When I transferred it, I remembered I had been given the instruction to deliver the aircraft to the approach controller at a speed of 250 knots maximum*, which was an unusual configuration for me. So, I thought I should check the speed before transferring. I didn't have the strip under my eyes anymore to check".

This was an error. The controller had forgotten the aircraft speed. It was a preventive measure to clear a doubt for safety and team work purposes. The situation was not risky. The following table indicates the original errors classified into the three new sub-categories.

Table 5.3.4: Detail of Correct Actions, Expert Judgement Deviations and Performance Errors

Simulation Sessions	CA	EJD	PE	Total Observations
S1 - EnRoute	2	7	4	13
S1 - Approach	3	20	3	26
S2 - EnRoute	3	13	2	18
S2 - Approach	2	12	5	19
S3 - EnRoute	2	7	0	9
S3 - Approach	3	9	4	16
Total	**15**	**68**	**18**	**101**
Percentages	*14.8%*	*67.3%*	*17.8%*	*100%*

Sixty seven percent of all observations fell into the Expert Judgement Deviation category, which represents the majority of controller behaviour and practice. Almost 18% of the original observed errors were actual Performance Errors, and 15% were standard or correct actions.

With reference to the sub-categories of the Expert Judgement Deviation and Performance Error (figure 5.3.3) an analyses of common practice, violations and errors was undertaken. The breakdown of these categories can be seen in the following table.

Table 5.3.5: Violations within the Expert Judgement Deviation and Performance Error Categories

Simulation Sessions	**Expert Judgement Deviations**		**Performance Errors**	
	Common practices	Violations that succeeded	Violations that failed	Errors
S1- En Route	3	4	0	4
S1- Approach	19	1	0	3
S2- En Route	12	1	0	2
S2- Approach	11	1	1	4
S3- En Route	5	2	0	0
S3- Approach	9	0	0	4
Total	**59**	**9**	**1**	**17**
Total violations		**10**		
Percentages	*58.4%*	*9.9%*		*16.8%*

Fifty eight per cent of the Expert Judgement Deviations were common practice. Violations accounted for approximately ten percent of the events and 17% were classified as Performance Errors.

Lastly the analysis technique, discussed in study 1, was used to more clearly identify the cognitive categories associated with the Expert Judgement Deviations and Performance Errors. There were a total of 76 of these events recorded.

Table 5.3.6 : Summary of the error analyses

Error Category*	Number Recorded	Prevention [12]	Detection [13]	Recovery [14]	Team Related
Perception & Vigilance					
no detection (visual)	2	Nil	Nil	Nil	-
no identification (visual)	3	Nil	Nil	NIl	-
hearback	3	Nil	2P	2RC	2
Working Memory					
forget planned action	6	Nil	2PC	2RC	2
inaccurate recall of information	3	Nil	2RC	2RC	-
forget temporary information	6	Nil	3RC	3RC	-
Long -Term Memory					
no recall of information	4	Nil	3RC	3PC	3
Judgement, Planning & Decision Making					
misprojection of aircraft	8	Nil	6PC	6RC	5
incorrect decision or plan	9	Nil	5PC/1RC	5RC	5
late decision or plan	5	Nil	3PC/1P	3PC/1RC	4
no decision or plan	4	Nil	Nil	Nil	-
Response Execution					
wrong positioning	5	Nil	Nil	Nil	-
wrong keying	8	Nil	2PC	2RC	2
wrong communication	10	Nil	5P	5RC	5
TOTAL	**76**	**-**	**35**	**34**	**28**

The results indicated that the category with the largest number of 'erroneous events'[15] was Judgement, Planning and Decision Making with 26 (34%), followed by

* As in the technique discussed in study 1
[12] P- Pilot, RC- Radar Controller, PC- Planning Controller
[13] P- Pilot, RC- Radar Controller, PC- Planning Controller
[14] P- Pilot, RC- Radar Controller, PC- Planning Controller
[15] Erroneous events refer to all events classified as Expert Judgement Deviations and Performance Errors

Response Execution with 23 (30%). This is a similar profile to the previous results from the first exercise.

There were 38 contextual conditions recorded which were associated with the above 'erroneous events'. The strong effect of the simulation context appeared on 16 occasions (41%). Thirteen of the contextual conditions (33%) were linked to traffic and airspace specifications, which was precisely what was being tested in this simulation. Team related issues (communication, co-ordination and procedures) accounted for 9 (25%) of the remaining conditions.

Among all the errors observed 45% were detected and recovered, 54% were neither detected nor recovered and one error was detected but not recovered.

In order to better define the team related issues, the task categories of the observed errors and violations were analysed and can be seen in the following table.

Table 5.3.7: Task categories of errors and violations

Task	Errors	Violations	Total Number
Instruction and clearance	8	5	13
Coordination between sectors	2	3	5
Conflict resolution	2		2
Readback		2	2
Control room communication between sector /instructions	1		1
HMI input and functions	1		1
Planning	1		1
Radar monitoring	1		1
Total	**16**	**10**	**26**

Fifty percent (13) of the errors and violations observed involved instruction or clearance delivery by the controller. Nineteen percent (5) of errors and violations observed involved co-ordination between sectors. This may be explained by the simulation since the air space sharing between sectors was sometimes understood differently amongst the controllers. Errors and violations also concerned problems between the individuals in the team structure. A total of 21 (81%) errors and violations were concerned with the tasks associated with team dynamics which reflects the importance of these issues in the generation of error prone performance.

Generally the results indicate that:

- with a total observation time of approximately 6 hours, the observed error rate was 2.8, that is between two and three errors committed in an hour. This result is complimentary to the classical error rate of experts in other working environments. The violation rate is also quite similar to other environments; that is between 1 and 2 violations committed per hour.
- the ability for controllers to prevent any potential errors was not apparent.
- the experimental design allowed the observers to gather invaluable information in the interview which led to the establishment of a new category of behaviour – Expert Judgement Deviation.
- team related issues were recognised within the majority of error and violation categories.

5.3.6 Findings and implications

This study presented the methods proposed to observe controller errors and violations in real-time simulated environments, as well as the analyses, with the human error technique, of the data gathered in the two simulations.

There were several predicted problems which were realised during the simulation exercises. Firstly there had to be a precise definition of error and violation which was understood by all observers. Secondly the method required not only an expert in the ATC environment, to understand the thinking behind many of the controller activities, but also the support of a human factor specialist to interpret many of the behaviours from a human information processing standpoint. Thirdly the observation methodology had to be thorough in order to elicit the thinking behind the observed erroneous or outstanding events. This method had to include the questioning of the controllers own thinking with respect to their error management strategies. Lastly the method had to take into account the sensitivities of all the professionals involved and present clear and precise goals in the observation environment.

The main results from the simulation observations illustrated the diversity of errors made, but indicated that the majority of errors were found in the planning and decision making category. More importantly the observation and interview activities explored the reasons why controllers made decisions about some of the events noted. It was realised that as expert decision makers, within the ATC environment, they were able to judge the displayed information and action a response which was

not obvious to the observers present. Once questioned the controllers were able to explain their chosen actions, or inaction, and this behaviour was labelled Expert Judgement Deviation.

The findings regarding how the team dynamics affect the ATM system were inferred by several of the analyses. Firstly the ability of another member of the team to detect and /or recover the erroneous event was demonstrated in both simulation exercises. The first simulation exercise showed that the planning controller and pilot had the most success in the perception and vigilance error category to communicate the error for the radar controller to recover. Few errors in the other error categories were recovered which may be due to the rather extreme simulation environment in which the controllers were working. Despite this, over half of all the errors were recovered. The second simulation exercise had a slightly different result, although 45% of errors detected were recovered. The highest number of errors recovered (54%) appeared in the Judgement, Planning and Decision Making category. This possibly reflected the influence of the better understanding of the other members of the team (planning controller and pilot) with regard to the mental model of the flight dynamics, and their willingness to communicate any uncertainty to the radar controller. This was also confirmed in some of the text recorded from the auto-confrontation interviews. Perhaps one of the most critical findings from this simulation exercises was the fact that team related issues were found in 80% of the error and violation categories.
It was also clear that approximately 62% of erroneous events were associated with communication, either between controller and pilot or between controllers, and 20% of erroneous events implicated co-ordination activities. There was also evidence, particularly from the auto-confrontation interviews, that shared understanding or mental model of the traffic was important for successful decision making. Assumptions associated with these situations led to violations and risky decisions. The model developed in section 4.3 seemed to be complimented by these results and may prove to be a sound basis for future work in this domain.

The final method proved to be efficient in terms of data gathering, since only a few of the analysable events lacked data. Sufficient data was also gathered with the observation methods to apply the human error technique to the errors and violations observed. The method also highlighted valuable information about how air traffic controllers actually work, how they use expert judgement to deviate from planned or prescribed practice within the system margins and manage safety.

CHAPTER 6. DISCUSSION

Air traffic control has a long history of safe operation and it is well known that controllers are expected to maintain highly proficient performance as part of a complex socio-technical system. However technology developments in the work environment have changed, in some cases quite dramatically, the nature of many tasks. With these changes, the controllers are being required to develop different strategies that in many situations include a change of dependence from individual resources to the support of others. Recent evidence of these changes can be seen with the introduction of an experimental concept known as Free Route airspace, in which not only did the amount of communication between controllers change, but the style and type of communication also altered.

It has been known for many years that the human contribution to errors in these high reliability systems is in the range of 70-90%, however experimental work associated with these issues in air traffic management is negligible. As a result of the dearth of information in this environment, several studies were proposed in order to ascertain, not only the underlying problems of individual error, but how these could be recognised, detected and recovered.

Two major activities were undertaken in the first study that employed two new methodologies of error analysis. The first, an adaptation of the Human Error in ATM (HERA) technique, revealed that, despite the problems of re-analysis of incidents from different countries, the majority of errors were found in the judgement, planning and decision making domain. However what was not predicted was the high number of errors which involved perception and vigilance, and in particular the problem of expectation and monitoring. This led to the non detection of visual information and hearback errors which were associated with team functions.

Team factors were also identified as the most common contextual conditions associated with the errors in the incidents, particularly co-ordination between sectors and misunderstandings between controllers. Although not surprising, the fact that it was the most influential of all the eleven contextual conditions was not predicted. This led to the second activity which was to create a matrix of interdependent activities as they appeared in the chronology of the incident, known as Joint Error Development of Incidents - JEDI. This method again revealed the strong link with other members of the team, whether they were pilots or controllers. Perhaps more importantly it revealed how the team members were prevented from recognising the

error and assisting recovery, and the strong influence of the ATM environment in this process.

The second study attempted to collect data from controllers themselves about the issues of team performance, error and safety. Although not statistically significant, the results indicated that the majority of controllers believed that team communication and understanding was critical to safety. The most interesting responses from this questionnaire survey involved the strong belief in discussion of uncertainty, communication between the controllers, information exchange and agreement of planning decisions. These issues therefore became the basis of the observation protocols in study three.

The third study was designed to explore erroneous behaviours within the ATM operational environment. As this had not been attempted in this domain, two complimentary activities were planned. Firstly, the recording of activity, including erroneous events was undertaken during several ATM simulation sessions. Initial results revealed a similar finding to the incident analyses in study 1. Most errors were classified in the judgement and decision making areas with the errors of hearback in perception and vigilance the most problematic. Perhaps more interesting was the ability of the other members of the team to help in the detection and recovery of errors; results indicated that the team members captured 21% of the errors recorded. However it was known from other research in ecological psychology that human behaviours, such as poor decision making, situation assessment and the reluctance to recover error, are in fact adaptive behaviours aimed at a compromise between the costs and benefits in complex situations (Zsambok and Klein, 1997: Amalberti, 2001). It was recognised that this first simulation was ambitious as it had a high degree of new technology which was being monitored, in fact 20 errors were due to a machine alerting system. It was thought therefore that assistance from machines aimed at assisting some tasks and consequently suppressing natural behaviour could paradoxically result in an inappropriate division of attention or excessive workload. In other words, the cognitive control of situations, particularly in the air traffic management environment, will usually demand a continuous compromise of different issues such as time available, task priorities and available resources.

It was for this reason that a second activity was undertaken to more thoroughly investigate the errors by systematically questioning the controllers after the recorded simulation session. This second simulation activity was also undertaken on a more stable platform (in terms of technology) with very few procedures which were new to the controllers.

This activity revealed some surprising and exciting results. The interviews indicated that in fact over half the erroneous events recorded were a category of behaviour, based on the cognitive control of the situation, which were labelled 'Expert Judgement Deviation'. These deviations were based either on common practices or violations which in the circumstances were successful. However these violations carried a risk which was related to the understanding of the other team members; in other words the controller taking the risk was convinced that the other controller (or pilot) understood and would respond as anticipated. Results also revealed that 10% of activities in the Expert Judgement Deviation and Performance Error category were violations. It was again indicated that almost half the errors were detected and recovered and that team tasks were involved in over 80% of these events. These team tasks included communication between controllers and pilots and co-ordination between sectors.

The recovery of errors was a little more difficult to confirm. Firstly the error analysis technique used in this work was based on a very detailed classification of information processing factors and their cognitive derivatives. Rasmussen's error analysis (1983) describes three levels of behaviour classed according to the control exercised over the action along with the situation. Rasmussen's three levels were labelled, skill-based behaviour which is mainly automatic, rule-based behaviour which is conscious and automatic, and knowledge-based behaviour which is mainly conscious. Rasmussen's mistakes classification is concerned with the rule and knowledge-based levels of behaviour. When analysing the errors in the simulation exercises the categories of memory and judgement, planning and decision making are the relevant categories of behaviour to be considered. In the simulation exercises 36% and 33% of errors were recovered in these categories respectively. In both cases these figures represented twice the number of errors recovered in all other categories.

This research has established that error plays an ecological role in the control of performance in the ATM environment, that is the controllers performance is characterised by different areas of expert judgement. At one end of performance, the controller believes they are in control and the situation is safe, and at the other end the situation may be beyond their control when mental alarm signals indicate an increasing risk. These performance parameters, rather than eliminating errors, tend to increase this spontaneous cognitive control. However it would also seem that technology and automated devices can mask the cognitive control function and cause problems for the controller to calculate the risks involved. This work has also

illustrated that the flow of error is regulated by cognition, and that the detection of errors play an important role in the maintenance of situation awareness.

It is also acknowledges from the general literature that highly effective teams are those which adapt in stressful situations by using effective co-ordination strategies. This is achieved by ensuring that all members of the team use a shared schema or mental model of the situation. Effective co-ordination is also reliant on good, clear and unambiguous communication between individuals, skills which have been identified in this research.

CHAPTER 7. CONCLUSIONS

The present research attempted to explore the team dynamics within the air traffic management system, and more importantly, the relationship between these interdependencies and errors.

The first study explored the cognitive and contextual issues which were involved in air traffic control incidents and hypothesised that the majority of incidents would be concerned with erroneous judgement and decision making. Re-analysis of several air traffic management incidents supported this hypothesis and complimented other findings in similar working environments such as flying and nuclear power generation.

The second hypothesis predicted that the majority of errors would be concerned with the team, which included the pilots. This was also confirmed from the two major activities in the first study of this research.

Evidence from the first and second studies generated findings which supported the third hypothesis regarding the prevalence of communication and co-ordination failures and led to the development of the model offered in section 4.

The final hypothesis regarding the recovery of errors was a little more difficult to confirm. However when delineating the errors that would be categorised by Rasmussen's 'mistakes', that is errors associated with memory and decision making, the results confirmed the hypothesis. The results from both simulation exercises indicated a strong relationship with the type of errors made and the potential for their recovery.

Finally there should be a comment on the nature of the team in the ATM environment. It became apparent, within the results of study 1 and the final activities associated with the simulations, that the traditional definition and associated activities of a team are not wholly appropriate for this environment. Although the ATM team have a high level goal to separate air traffic in a safe and timely manner, the members of the teams involved have specific roles which are carried out in a very individualistic way. The following quote from a controller explains this situation very clearly:

> *"To be an air traffic controller is a very lonely job. The essence of the work, the separation of aircraft, is something you do solely by yourself. There is no teamwork involved in the decisions you have to make to keep them apart. These decisions are the core of the business. Every conflict has its own solution but always more than*

one. Depending on the situation every choice you make has its own consequences. You always have a choice between lateral or vertical separation. It is the outcome of your decision that determines which solution you choose. Do I go left or right? Do I go up or down? Do I slow down or speed up? These decisions have their consequences for the next conflict. That's how you develop the situation yourself and in the long run you end up with a traffic picture you created yourself. This also implies the personal preferences a controller can have. Some feel more confident with vertical separation and therefore will avoid lateral separation as much as possible. Some prefer the opposite. In all cases it is the individual that makes the decisions. However, these decisions do have their impact on the work of other air traffic controllers. You hardly ever work alone in a piece of air space, also the airspace you control borders the airspace of other air traffic controllers. This implies your decisions do have an influence on the work of a colleague, it is therefore very important that you let all the other colleagues involved know what your intentions are. This individual part of the work is thus fully depending on the information you have about the intentions of the aircraft you control and the intentions of your colleagues. This process of gathering information is very much reliant on good teamwork. You obtain this information mainly via co-ordination procedures, and that is of course also the way you give information. If this exchange of information hampers for whatever reason you will not be able to execute that individual part of your work, the essence of air traffic control - separating aircraft.
So one might say that being an air traffic controller is kind of a schizophrenic job. You have to be able to make the paramount decisions individually but you cannot do that if you're not a perfect team player."

M.D., 2002

It would therefore be more reasonable to consider the working arrangements within this domain as the interaction of 'dynamic sets', each controller working within common and strict rules and procedures, but with the ability to engage in short team process activity. This is a new phenomenon and one which has been developed from the literature and experimental research undertaken for this thesis. The essence of the 'dynamic set' can be graphically illustrated in chapter 4, figure 4.3. This figure

takes the three main identified elements of team interactions within the air traffic control environment; communication, co-ordination and shared mental model, and places them in a dynamic activity set.[16] It is suggested that although individuals work in this environment on their own, shown by the circles, they also work when required with others, shown by the overlapping circle sectors. Finally it is demonstrated that where all the main air traffic control activities overlap, there is opportunity in which the team can manage their errors and recovery unsafe situations.

7.1 Limitations of this research

The limitaions of this study come from several sources:

Firstly, the fact that although there has been a large body of knowledge which surrounds the teamwork literature, there has been virtually nothing written on this subject in air traffic control.

Secondly, the nature of error, particularly in the very 'private' domain of air traffic management has been rarely investigated. Therefore the basis of the investigative work is rather unique and therefore subject to incompleteness.

Lastly, and in some ways dependant on the first two issues, the findings provoke more questions than the original hypotheses had anticipated.

7.2 Recommendations for the future

Therefore in regard to the above, there are several recommendations which can be made with regard to future research:

- Further work in the investigation process with 'live' occurrences and in co-operation with incident investigators, would strenghten the data regarding the influence of 'dynamic sets' within this environment.
- Further observational work in the air traffic management environment would also enrich the present findings, and perhaps a more precise protocol with a specific 'dynamic set' matrix of observable behaviours would strengthen the findings already discussed.

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[16] The term set is derived from set theory, a branch of mathematics concerned with the properties of sets, which distinguishes a number of people grouped or belonging together.

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Appendices

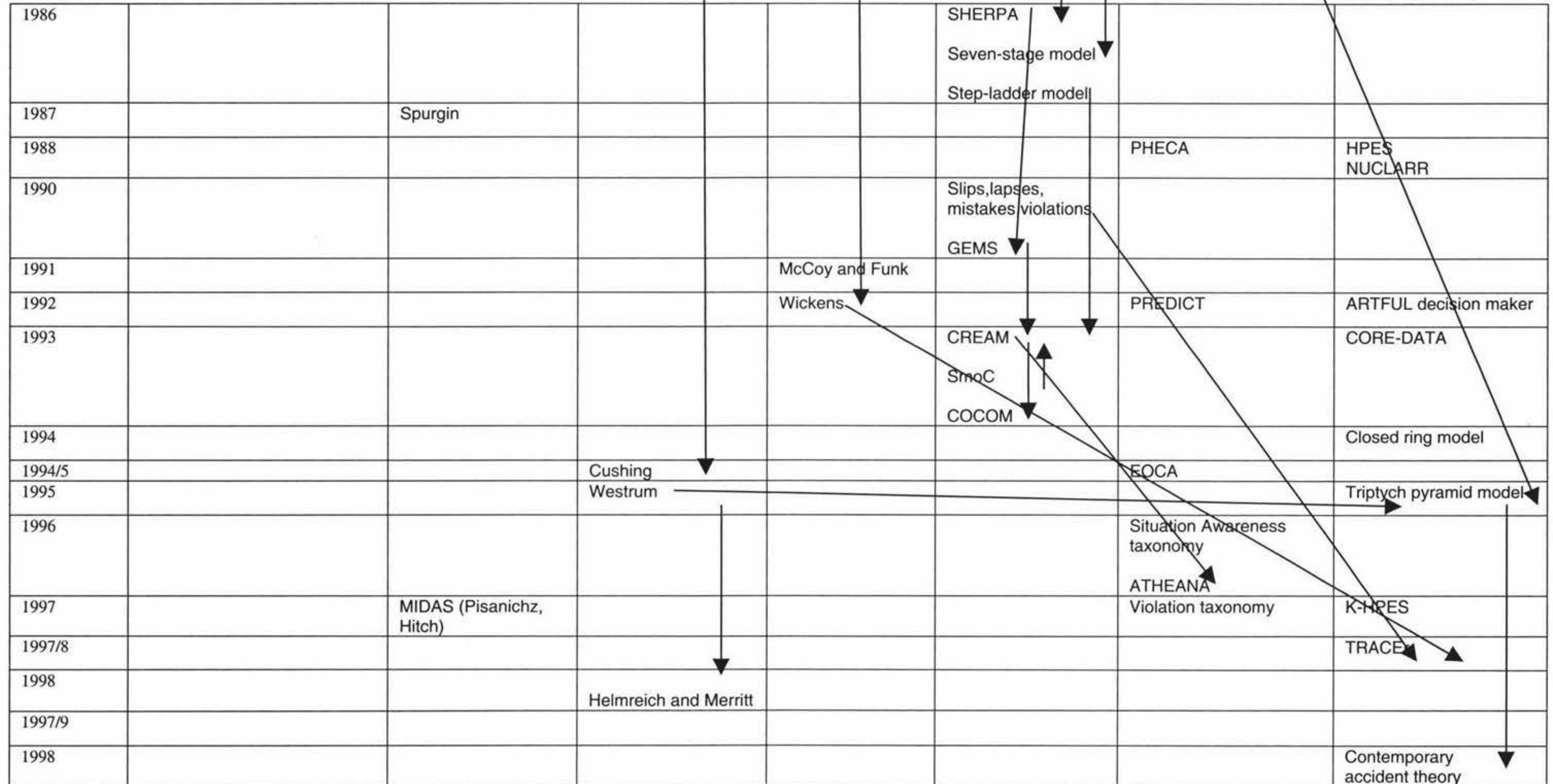
A Graphical link between the Human Error Approaches

B The Human Error in ATM (HERA) technique and example

C The Air Traffic Control Team Safety Questionnaire

Appendix A: Graphical link between the Human Error Approaches

Year or Publication	Task-based Taxonomies	System-oriented Taxonomies	Communication System Models-Taxonomies	Information Processing Models & Taxonomies	Symbolic Processing Models & Taxonomies	Other Models and Taxonomies	Other Domain Approaches: - Nuclear ATC, - Aviation
1948			Lasswell formula				
1949			Linear model				
1954			Circular model	Fitts			
1956				Miller			
1958				Broadbent			
1960			SMCR model	Welford			
1962				Payne & Altman			
1964				Berliner			
1967			Helical model				
1969			Andersch, Staats & Bostrom				
1975					Schmidt		
1976				Martinuik			
1979							
1980					Actions not as planned	Optimal control model	
1981			Grayson and Billings		SRK Model Action slips	Signal detection theory	
1982					Murphy diagrams Multi-faceted taxonomy		
1982/3	Error modes						
1983					Rouse and Rouse		
1985							Error in incident sequence



1986					SHERPA Seven-stage model Step-ladder model		
1987		Spurgin					
1988						PHECA	HPES NUCLARR
1990					Slips,lapses, mistakes violations GEMS		
1991				McCoy and Funk			
1992				Wickens		PREDICT	ARTFUL decision maker
1993					CREAM SmoC COCOM		CORE-DATA
1994							Closed ring model
1994/5			Cushing			EOCA	
1995			Westrum				Triptych pyramid model
1996						Situation Awareness taxonomy ATHEANA	
1997		MIDAS (Pisanichz, Hitch)				Violation taxonomy	K-HPES
1997/8							TRACE
1998			Helmreich and Merritt				
1997/9							
1998							Contemporary accident theory

Appendix B: The Human error in ATM (HERA) Technique and Example

HERA

The HERA technique was developed to assist Incident Investigators in occurrence investigation. The following tables contain all the information required for the investigation. These can be found in:

Error/Violation type,
Error Detail,
Error Mechanisms,
Information Processing level and
Contextual Conditions

Investigators will probably be able to identify the Error/Violation types and in most cases the Contextual Conditions associated with the errors listed from the written descriptions and the factual data (radar plot, R/T tapes) gathered.
From this evidence investigators in most cases will also be able to identify the Error Detail level. In these cases the investigators can then narrow their questioning at interview to the Error Detail level(s) identified and their associated Error Mechanism and Information Processing levels. If an investigator cannot verify the Error Detail level or suspects more than one Error Detail level before the interview, the interview will commence with the verification of this level before continuing to the associated Error Mechanism and Information Processing levels.
Lastly the investigators may have some ideas prior to the interview of the Contextual Conditions associated with the occurrence. However it is important that the investigator can verify or extend the scope of these issues during the interview with those personnel involved.

The following HERA document should assist investigators not only with the identification of the errors and the context in which they occur, but will assist the interview process to establish the more detailed issues found in the occurrence.

HERA sequence:

1. Gather all data, written and factual.
2. Identify the Error/Violation type.
3. Identify the Error Detail level and Contextual Conditions if possible.
4. At interview:
    - establish or verify firstly the error/violation made;
    - establish or verify the Error Detail level;
    - having identified the Error Detail level follow the appropriate Error Mechanism and Information Processing levels relevant;
    - establish the possible contextual conditions identified.
5. Check the remedial action appropriate for the Error Mechanism and Information Processing levels listed.

Note: *It is possible, that even with the most rigorous data gathering and interview, that the information at the Error Mechanism and Information Processing levels are difficult to identify.*

1. Error/Violation Type

Having read and gathered all relevant data, answer the following questions[1]:

1.1 Was the error involved with Timing of Action ☐ **Go to Section 1.1.1**

Was the error involved with Selection of Action ☐ **Go to Section 1.1.2**

Was the error involved with Information transfer/receipt
☐ **Go to Section 1.1.3**

1.2 Did the controller do something which contravened a rule or procedure
☐ **Go to Section 1.1.4**

1.1.1 Timing of action	**1.1.2 Selection of action**	**1.1.3 Information transfer/receipt**	**1.1.4 Violation**
Was the action:	Was the action:	Was the information:	Was the violation:
Too long/short ☐	Omitted ☐	Unclearly transmitted/sent ☐	Rule broken unintentionally ☐
Too early/late ☐	Too much/little ☐	Unclearly written/typed ☐	Situational ☐
Repeated ☐	In wrong direction ☐	Not received/ obtained ☐	Exceptional ☐
Mis-ordered ☐	Wrong action on right object ☐	Not transmitted/ sent ☐	General ☐
	Right action on wrong object ☐	Not written/ typed ☐	
	Wrong action on wrong object ☐	Incompletely transmitted/sent ☐	
	☐	Incompletely written/typed ☐	
		Incorrectly tranmistted/sent ☐	
		Incompletely written/typed ☐	

The Error/Violation is classified as -

[1] There will probably only be one category in this section. However this category may be classified either as an error or a violation or both, until an interview can verify the answer.

2. Error Detail level

Having read and gathered all relevant data, answer the following questions[2]:

2.1 Did the controller **miss information -** *mishear / mis-see / not detect / detect late*

YES ☐ **Go to Section 3.1**
NO / DON'T KNOW ☐ **Go to Section 2.2**

2.2 Did the controller **forget information –** *stored information / recent information / future actions*

YES ☐ **Go to Section 3.2**
NO / DON'T KNOW ☐ **Go to Section 2.3**

2.3 Did the controller **misjudge information –** *error in planning / problem-solving / decision-making*

YES ☐ **Go to Section 3.3**
NO / DON'T KNOW ☐ **Go to Section 2.4**

2.4 Did the controller **make an action error** – performing physical action / speech

YES ☐ **Go to Section 3.4**
NO / DON'T KNOW ☐ **Go to Section 2.1**

The Error Detail is classified as -

The investigator should only ask those questions in Section 3 relevant to the Error Detail level identified above. If this category is not known or there is uncertainty the investigator can systematically follow each of the 4 options in Section 3 [Perception and Vigilance, Memory, Judgement or Response Execution]. If the investigator is confident of the Error Detail level they should only ask questions relevant to that option in Section 3.

[2] There should only be one category in this section. Again if 2 or more are suspected the personnel must be interviewed to narrow the choices to 1.

3. Error Mechanism (EM) and Information Processing level (IP)

The exact nature of the Error Mechanisms (EMs) and Information Processing levels (IPs) must be verified with questions at interview. The investigator should systematically work down the list of EMs and then again systematically down the IPs of the Error Detail (ED) concerned. There should only be one EM and one IP chosen for each ED. As soon as a match is made in either the EM or IP then the investigator should go to Section 4 – Contextual Conditions. If no matches can be found the investigator should verify they have chosen the correct ED. If the investigator still cannot ascertain the correct match, they should leave the analysis and go to Section 4 – Contextual Conditions.

3.1 Information Missed – Perception and Vigilance Errors

3.1.1 Perception and Vigilance EM ***Did you ...? or Did the controller....?***	**3.1.2 Perception and Vigilance IP** ***Did you ...? or Did the controller....?***
Hear incorrect/weak/obscured information ☐ - Go to Section 4	Fail to detect information after visual search ☐ - Visual search failure
Detect but mishear auditory information ☐ - No detection	Fail to monitor people/information/ automation ☐ - Monitoring failure
Mishear/confuse auditory information ☐ - Misheard	Have a strong expectation /mindset about the information ☐ - Expectation bias
Recognise auditory information too late ☐ - Late auditory recognition	Wrongly associate incoming information with something else ☐ - Association bias
Have a pilot read back of instruction ☐ - Hearback	Confuse separately but closely displayed information ☐ - Information confusion
Mis-identify/confuse visual information ☐ - Mis-identification	See information which sounded/looked like others ☐ - Information confusion
Misread information ☐ - Misreading	See information which was not identified because of size/brightness/loudness ☐ - Discrimination problem
Mis-perceive information ☐ - Mis-perception	See information which was on the edge of display ☐ - Out of sight bias
Fail to make a visual search ☐ - Go to Section 3.3	Fixate/tunnel on prominent information ☐ - Tunnelling
Fail to detect or detect late visual information ☐ - No/late visual detection	Have too much information or work with ☐ - Information overload
Fail to identify or identify late visual information ☐ - No/late visual identification	Have too little information or work with ☐ - Vigilance problem
	Have a momentary distraction or long-term preoccupation ☐ - Distraction/preoccupation

Error Detail identified -

Information Processing level identified -

3.2 Information Forgotten – Memory Errors

The instructions for the investigator for this section are exactly the same as for Section 3.1.

3.2.1 Memory EM - ***Did you … ? or Did the controller….?***	**3.2.2 Memory IP –** ***Did you … ? or Did the controller….?***
Forget to monitor a/c ☐ - Forget to monitor	Forget/lose awareness of equipment mode ☐ - Equipment mode error
Forget to perform action ☐ - Forget planned action	Get confused because of similar information ☐ - Similarity of information
Perform an action too late ☐ - Forget to p7erform action	Have too much information to work with ☐ - Memory capacity overload
Forget already carried out action ☐ - Forget previous action	Have a distraction or preoccupation during work ☐ - Distraction/Preoccupation
Forget information in working memory ☐ - No/inaccurate recall of temporary information	Feel that stored information interfered with recalled information ☐ - Negative transfer of information
Have inaccurate recall of stored information ☐ - Mis-recall of information in long-term memory	Feel that the information was stored incorrectly or not learned properly ☐ - Mis-stored/not learned information
Have no recall of stored information ☐ - No recall of information in long-term memory	Consider the information was rarely used ☐ - Rarely used information

Error Detail identified -

Information Processing level identified -

3.3 Information Misjudged – Planning and Decision-making

The instructions for the investigator for this section are exactly the same as for Sections 3.1 and 3.2.

3.3.1 Planning and Decision-making EM – ***Did you ... ? or Did the controller....?***	**3.3.2 Planning and Decision-making IP –** ***Did you ... ? or Did the controller....?***
Misjudge the projection (time/ space) of a/c ☐ - Misjudge a/c projection	Have incorrect / mis-stored knowledge ☐ - Incorrect knowledge
Make an incorrect decision/plan for a/c ☐ - Incorrect decision/plan	Have lack of knowledge ☐ - Lack of knowledge
Make a late decision/plan for a/c ☐ - Late decision/plan	Fail to consider side effects and future situation ☐ - Prospective memory failure
Make no decision/plan ☐ - No decision/plan	Fail to integrate information ☐ - Information integration failure
Make an insufficient plan for a/c ☐ - Insufficient plan	Fixate on a specific plan ☐ - Fixation
	Wrongly assume information ☐ - Incorrect assumption
	Fail to prioritise high importance tasks ☐ - Incorrect priority of task
	Fail to convey the danger involved because of pride/overconfidence ☐ - Incorrect assumption
	Fail to convey the danger involved for others reasons ☐ - Failed to recognise risk

Error Detail identified -

Information Processing level identified –

3.4 Action Error – Response Execution

The instructions for the investigator for this section are exactly the same as for Sections 3.1, 3.2. and 3.3.

3.4.1 Response Execution EM – *Did you …? Or Did the controller….?*	**3.4.2 Response Execution IP –** *Did you …? or Did the controller….?*
Make an error in typing ☐ - Typing error	Perform an action due to strong habit ☐ - Problem of habit
Make an error in selecting an object ☐ - Selection error	Confuse objects to be selected ☐ - Spatial confusion
Make an error in positioning an object ☐ - Positioning error	Incorrectly perform action because it was too precise ☐ - Lack of manual precision
Mistime an action/communication ☐ - Timing error	Confuse the look of the object ☐ - Problem of similar look
Transmit or record indistinct information ☐ - Unclear information transmitted/recorded	Deliver a message with pauses/stammers/ mumbling ☐ - Unclear speech
Transmit or record incorrect or inaccurate information ☐ - Incorrect information transmitted/recorded	Deliver a message with inappropriate tone ☐ - Wrong voice tone
Fail to transmit/record information ☐ - Information not transmitted/recorded	Deliver an incorrect instruction in relation to turn/heading ☐ - Spatial confusion
Fail to carry out other actions ☐ - Omission of action	Perform an action due to a 'triggering' thought ☐ - Intrusion of habit
	Perform an action or speech whilst being interrupted ☐ - Interruption from environment
	Perform an action or speech which was unintended ☐ - Slip of the pen/tongue

Error Detail identified -

Information Processing level identified -

4.0 Contextual Conditions

Contextual Conditions are all those conditions which could be found in the error and occurrence scenario. These are just as important as the cognitive failures which have been identified in the above sections.
The Contextual Conditions are found in 11 groupings. Details of each grouping can be found as follows:

1. *Pilot-Controller Communications – Section 4.1*
2. *Pilot Actions – Section 4.2*
3. *Traffic and Airspace – Section 4.3*
4. *Weather – Section 4.4*
5. *Documentation and Procedures – Section 4.5*
6. *Training and Experience – Section 4.6*
7. *Workplace Design and HMI – Section 4.7*
8. *Environment – Section 4.8*
9. *Personnel Factors – Section 4.9*
10. *Team Factors – Section 4.10*
11. *Organisational Factors – Section 4.11*

Unless the investigation has clearly shown those issues above which are related to the occurrence the investigator should address each section in turn and ask the relevant questions listed.

In this occurrence were you concerned with any of the following pilot communication and/or actions?

4.1 Pilot-Controller Communications *Was there...?*		4.2 Pilot Actions *Were any of these problems...?*	
Pilot language/accent difficulties	☐	Responding to TCAS Alert	☐
Similar confusable call signs	☐	Response time to ATC instructions	☐
Pilot readback incorrect	☐	Correct pilot readback followed by incorrect action	☐
Pilot experience	☐	Rate of turn	☐
Situation not conveyed by pilots – urgency/party-line support	☐	Rate of climb/descent	☐
Pilot breach of R/T standards/ phraseology	☐	A/C navigational limitations not considered by pilot	☐
ATC breach of R/T standards/ phraseology	☐	Other – State	
Speech tone	☐		
Speech rate	☐		
Complexity of ATC transmission	☐		
Pilot high/excessive R/T workload	☐		
ATC high/excessive R/T workload	☐		
A/C stuck transmitter	☐		
R/T interference	☐		
R/T cross-transmission	☐		
R/T blocked frequency	☐		
Other – State			

Pilot-communication problems -

Pilot actions -

In this occurrence did you consider either traffic and airspace or weather as a factor in your work?

4.3 Traffic and Airspace ***Was there a problem with...?***		**4.4 Weather** ***Was there a problem with...?*** ***Type***		***Consequence***	
Sector capacity limitations	☐	Snow/ice/slush	☐	Taxi problems	☐
Excessive traffic load	☐	Fog/low cloud	☐	Route deviation	☐
Complex traffic mix	☐	Thunderstorm	☐	Holding patterns	☐
Fluctuating traffic load with unexpected demands – off route traffic	☐	Extreme winds at high altitude	☐	Vectoring problem/abilities	☐
Holding patters	☐	Extreme surface winds	☐	Difficulty tracking aircraft/vehicles	☐
Aircraft with similar/confusable call signs	☐	Downdraft/ Windshear	☐		
Underload	☐	Other - State			
Speech tone	☐				
Post peak traffic	☐				
Unusual situation – emergency or high risk	☐				
Flight in non-controlled and controlled airspace	☐				
IFR/VFR mix	☐				
Flight in transitional airspace	☐				
Airspace design characteristics – complexity, changes	☐				
Traffic management initiatives	☐				
Temporary sector activities - *TYPE*					
Military	☐				
Medical	☐				
Parachuting	☐				
Student pilot	☐				
State flight	☐				
Other State					

Traffic and Airspace problems -

Weather problems -

Did the following issues regarding Documentation and Procedures affect your work?

4.5 Documentation and Procedures							
Documentation *Was there a problem with...?*				**Procedures** *Was there a problem with...?*			
Type		***Problem***		***Type***		***Problem***	
Orders	☐	Unclear	☐	Arrival	☐	Unclear	☐
Charts/notices	☐	Contradictory	☐	Landing	☐	Contradictory	☐
Temporary notices	☐	Ambiguous	☐	Special arrival procedures	☐	Ambiguous	☐
Advisory manuals	☐	Incorrect	☐	Land & hold short	☐	Incomplete	☐
Checklists	☐	Incomplete	☐	Clearing runway	☐	Inaccurate	☐
Automated references	☐	Inaccurate	☐	Simultaneous use of same runway	☐	Too complex	☐
Special information NOTAMs,SIGMETs	☐	Too complex	☐	Crossing runway	☐	New/recent changes	☐
Other - State		New/recent changes	☐	Taxi & hold short	☐	In revision	☐
		In revision	☐	Departure	☐	Outdated	☐
		Outdated	☐	Wake turbulence	☐	Not available	☐
		Not available	☐	Visual separation	☐	Other - State	
		Other - State		En-route	☐		
				Oceanic	☐		
				Noise abatement	☐		
				Other – State			

Documentation problems -

Procedure problems -

Did you consider following issues regarding Training and Experience affected your work?

4.6 Training and Experience ***Was there a problem with...?***	
Inadequate knowledge for position	☐
Inadequate experience on position	☐
Inadequate time on position	☐
Unfamiliar task in routine operations	☐
Novel situation	☐
Over-training	☐
Inadequate mentoring	☐
Inadequate on the job training	☐
Inadequate emergency training	☐
Inadequate team resource management training	☐
Inadequate recurrent/continuation training	☐
Controller under training	☐
Controller under examination/check	☐
Other – State	

Training and Experience problems -

Was there a problem with Workplace Design, HMI or the Environment?

4.7 Workplace Design and HMI *Type*		*Problem*		**4.8 Environment**	
Working position/ console, e.g. HMI	☐	Conflicting information	☐	Noise from people	☐
Surveillance, e.g. radar	☐	Failed/broken equipment	☐	Noise from equipment	☐
Communication, e.g. radio	☐	False information	☐	Distraction – job-related	☐
Navigation, e.g. approach aids	☐	Feedback problem	☐	Distraction – non – job-related	☐
Flight information display, e.g. FPS and display	☐	High false alarm rate	☐	Air quality	☐
Auxiliary equipment, e.g. generators	☐	Illegible information	☐	Lighting problems	☐
Other information display, e.g. weather	☐	Inaccessible information	☐	Pollution/fumes	☐
Equipment warning devices, e.g. alarms/alerts	☐	Incorrect information	☐	Asbestos	☐
Other - State		Interference	☐	Radiation	☐
		Lack of equipment/information	☐	Other - State	
		Lack of coverage/range	☐		
		Lack of precision	☐		
		Lost information	☐		
		Mode confusion	☐		
		No equipment/information	☐		
		Nuisance information	☐		
		Poor design	☐		
		Poor display	☐		
		Poor positioning	☐		
		Recently introduced equipment/information	☐		
		Equipment size problem	☐		
		Suppressed information	☐		
		Unavailable equipment/ information	☐		
		Unclear equipment/information	☐		
		Unreliable equipment/information	☐		
		Untrustworthy equipment/information	☐		
		Visibility of equipment/information	☐		
		Other – State			

Training and Experience problems –

Environment problems-

Were you or your colleagues effected by any of the following issues?

4.9 Personal Factors ***Where you …?***		**4.10 Team Factors** ***Was there …?***	
Distracted by personal thoughts	☐	Adequate assistance from controllers	☐
Incapacitated by illness/collapse	☐	Adequate and current equipment	☐
Having general health problems – nutrition/hydration/exercise	☐	Adequate and complete relief briefing	☐
Impaired due to alcohol/medication/drugs	☐	Cooperative effort on everyone's part within and between sectors/facilities	☐
Fatigued due to tiredness	☐	Conflict/personality problems within and between sectors and facilities	☐
Fatigued due to sleep loss	☐	A problem with late returns to position after breaks	☐
Fatigued due to sleep deprivation	☐	A problem with temporarily unstaffed positions	☐
In pain	☐	A problem with temporary team assignment	☐
Suffering abnormal stress – post incident/training/checking	☐	A problem with controllers showing a lack of responsibility	☐
Suffering from high anxiety/panic	☐	A problem with controllers using unclear working methods	☐
Suffering from domestic/lifestyle problems	☐	A problem with controllers confidence in others	☐
Suffering from emotional stress	☐	A problem of team pressure	☐
Suffering from boredom	☐	A problem with supervisors cooperating with staffing and traffic flow	☐
Suffering from complacency	☐	A problem of personnel – flight data/ maintenance supporting operations	☐
Suffering from lack of confidence	☐	A problem of management support	☐
Suffering from lack of trust in automation	☐	A problem of other units support	☐
Suffering from lack of motivation/ morale	☐	A problem of staffing in the unit	☐
Lacking duty of care	☐	A problem of confidence in the supervision	☐
Other- State		A problem of cooperation amongst supervisors	☐
		A problem of cooperation amongst management	☐
		A problem of cooperation in higher management	☐
		Other –State	

Personal problems -

Team problems -

At the end of the interview concerning a specific incident ask all the following questions if appropriate

4.11 Organisational Factors			
In general is your working environment positive?	Yes ☐	No ☐	Don't know ☐
Do you feel you have to chose between safety and efficiency when controlling traffic?	Yes ☐	No ☐	Don't know ☐
Do you consider your organisation balances safety and efficiency appropriately?	Yes ☐	No ☐	Don't know ☐
Do you consider that the number of qualified controllers at your facility is sufficient?	Yes ☐	No ☐	Don't know ☐
Generally are you satisfied with your job?	Yes ☐	No ☐	Don't know ☐
Do you think your roster/rest/duty times are adequate?	Yes ☐	No ☐	Don't know ☐
Do you think your scheduling is adequate?	Yes ☐	No ☐	Don't know ☐
In your opinion do most ATCOs follow the rules?	Yes ☐	No ☐	Don't know ☐
In your opinion do most supervisors follow the rules?	Yes ☐	No ☐	Don't know ☐
Do you agree with the terms and conditions governing your work?	Yes ☐	No ☐	Don't know ☐
Do your supervisory staff make appropriate decisions with regard to staffing and facilities?	Yes ☐	No ☐	Don't know ☐
Do your management staff make appropriate decisions with regard to staffing and facilities?	Yes ☐	No ☐	Don't know ☐
Are policies at your facilities carried out safely and efficiently by your supervisors?	Yes ☐	No ☐	Don't know ☐
Are policies at your facilities carried out safely and efficiently by your management?	Yes ☐	No ☐	Don't know ☐
Other organisational issues of concern – State			

Organisational problems –

Example using the HERA technique*

HERA INCIDENT ANALYSIS FORM			
DETAILS OF INCIDENT			
Reference:	AIRPROX (C) 24/96	**Date & Time:**	21 September 1996 1225 UTC
Country:	UK		
Aircraft:	B767/B747	**Operators:**	Foreign Airlines
Geographical position:	4nm South of Boulogne		
ALT/HT/FL:	FL310	**Airspace Type:**	UAR - Class B
Reporter:	LATCC - London Upper Sector Controller		
Reported Separation:	1.3nm horizontal/300 feet vertical		
Recorded Separation:	1.1nm horizontal/400 feet vertical		
HERA Analyst:	AI/SS		
BRIEF DESCRIPTION OF INCIDENT			
A B747 was en route from Zurich to New York, cruising at FL310 on UAR UB4 via Boulogne VOR to Brookmans Park. A B767 from Paris (Orly) to New York was routeing UB376, also via Boulogne VOR at FL180. Both aircraft were under the control of LUS. The traffic situation was described as busy, although the LUS was bandboxed. The CSC decided, in consultation with the off-going sector controller, that instead of splitting the sector into E and W, the off-going controller would be used as a support controller to the relief controller. Most of the traffic was on the East side, so it was thought that splitting the sector would be unproductive. The relief controller, who had little experience of this mode of operation, agreed to the plan. The B747 pilot reported level at FL310 on first contact, and was instructed to maintain FL310 and given a routeing of Boulogne, Brookmans Park and Trent. Shortly afterwards the B767 pilot established RTF contact with the LUS reporting approaching Boulogne at FL280 - the expected level as indicated on the fps. However, the Sector controller erroneously instructed the B767 pilot to "Maintain FL310" **[1]**. The controller then turned her attention to other traffic and did not note the B767 pilot's reply "up to 310" **[2]**. The support controller did not hear the sector controller's call because he was concentrating his attention elsewhere (although there is no responsibility for a support controller to hear all the calls). However, the support controller noticed that the B767 was at FL283 Mode C, above FL280 as displayed on the fps. When he drew this to the attention of the Sector controller, she replied initially that the aircraft was not on frequency. Still concerned, the support controller continued to prompt the Sector controller into taking action to resolve the problem. He was convinced that the B767 pilot was on frequency because the Sector controller had ticked the callsign on the fps. Both he and the CSC tried to get the Sector controller's attention to contact the B767 pilot but, because she was busy making calls, they found it difficult to make her aware of the circumstances. The Sector controller still did not believe that the B767 was on frequency, because she did not remember its first call. Hence, she did not take any action, but they continued to prompt her to call the aircraft			

* Please note that the details in this example are highly confidential

HERA INCIDENT ANALYSIS FORM							
[3]. About thirty seconds after the STCA activated, she called the B767 pilot who responded immediately and was told "...turn left now avoiding action a heading of 350 confirm your cleared level was FL280?" The B767 pilot replied "...I'm sorry (callsign) left 350 and broke you up". The Sector controller replied "...Roger (callsign) there is traffic on your right hand side a range of 3 miles your cleared level was 280". The support controller estimated that about 40 seconds passed between him warning the Sector controller of the situation and her making her first warning call, but this was 'off-mike' and so was not recorded. At the point of the transmission to the B767 pilot the aircraft was passing FL296, 5.5nm from the B747, with both aircraft on converging headings. The Sector controller admitted that the initial avoiding action heading was not a good one because it was very similar to, or to the right of, the aircraft's track **[4]**. Also, the Sector controller assumed that by stating the aircraft's cleared level the B767 pilot would probably stop the climb, but she admitted that she should have used a more positive instruction to instruct the pilot to descend to FL280 or FL290 **[5]**. She also intended to call the B747 pilot to issue a right turn but she was pre-empted by the pilot reporting traffic at 10 o'clock climbing through his level in a simultaneous transmission with the B767 pilot trying to confirm his cleared level. The Sector controller then instructed the B747 pilot to turn right heading 030° for avoiding action. The B767 continued to climb and when it was seen passing FL307 the Sector controller instructed the pilot to stop his climb and descend to FL290 and to turn left heading 030° for avoiding action.							
Please record the individual errors in the sequence in which they occurred							
DESCRIPTION OF ERROR # 1							
The LUS sector controller erroneously instructed the B767 pilot to "Maintain FL310"							
How Detected:	Error not detected by Sector controller or support controller. Support controller later pointed out problem and STCA alerted.						
How Recovered:	Left avoiding action turn						
Causal	✔	**Contributory**		**Compounding**		**Non-contributory**	
HERA CLASSIFICATIONS							
Task:	RT communications/instructions						
Information/ Equipment:	Flight Level /radar						
ET:	Incorrect information transmitted Extraneous Act						
ED:	Response Execution						
EM:	Incorrect information transmitted						
IP:	Thoughts leading to actions						
CC:	N/A						
Reporter's assumptions:	(i) "(The Panel) accepted that it was likely that this was a slip-of-the-tongue by the controller which was possibly because she had just instructed the B747 pilot to maintain FL310 and that this figure was still in her mind."						
Analyst's assumptions:	N/A						
NOTES							

<table>
<tr><th colspan="8">HERA INCIDENT ANALYSIS FORM</th></tr>
<tr><td colspan="8">(ii) Alternatively, it could be that the sector controller misheard the B767 pilot's callsign and believed it was the B747 calling a second time, or that the controller forgot that the B747's first call, and expected the call to be from the B747 pilot.
(iii) Review by AIRPROX panel states that the scenario was not unusually busy for this sector or for the time of day.</td></tr>
<tr><th colspan="8">DESCRIPTION OF ERROR # 2</th></tr>
<tr><td colspan="8">The LUS sector controller turned her attention to other traffic and did not note the B767 pilot's reply "up to 310".</td></tr>
<tr><td colspan="2">How Detected:</td><td colspan="6">Error not detected by Sector controller or support controller. Support controller later pointed out problem and STCA alerted.</td></tr>
<tr><td colspan="2">How Recovered:</td><td colspan="6">Left avoiding action turn</td></tr>
<tr><td>Causal</td><td>✔</td><td>Contributory</td><td></td><td>Compounding</td><td></td><td>Non-contributory</td><td></td></tr>
<tr><th colspan="8">HERA CLASSIFICATIONS</th></tr>
<tr><td colspan="2">Task:</td><td colspan="6">RT communications/instructions</td></tr>
<tr><td colspan="2">Information/ Equipment:</td><td colspan="6">Flight Level / radar</td></tr>
<tr><td colspan="2">ET:</td><td colspan="6">Omission</td></tr>
<tr><td colspan="2">ED:</td><td colspan="6">Perception and Vigilance</td></tr>
<tr><td colspan="2">EM:</td><td colspan="6">Hearback error</td></tr>
<tr><td colspan="2">IP:</td><td colspan="6">Unknown</td></tr>
<tr><td colspan="2">CC:</td><td colspan="6">N/A</td></tr>
<tr><td colspan="2">Reporter's assumptions:</td><td colspan="6">N/A</td></tr>
<tr><td colspan="2">Analyst's assumptions:</td><td colspan="6">N/A</td></tr>
<tr><th colspan="8">NOTES</th></tr>
<tr><td colspan="8">(i) Possibly 'Expectation bias' or 'Distraction' (the AIRPROX Panel state that "The JAAP thought that the significance of the 'up to three one zero' escaped the controller's notice because the pilot went on immediately '...er...say again the clearance', i.e. his routeing; when the controller was already waiting to transmit to two other aircraft not involved in the AIRPROX".</td></tr>
<tr><th colspan="8">DESCRIPTION OF ERROR # 3</th></tr>
<tr><td colspan="8">The LUS sector controller did not believe that the B767 was on frequency, because she did not remember its first call. Hence, she did not take any action.</td></tr>
<tr><td colspan="2">How Detected:</td><td colspan="6">N/A</td></tr>
<tr><td colspan="2">How Recovered:</td><td colspan="6">Left avoiding action turn</td></tr>
<tr><td>Causal</td><td></td><td>Contributory</td><td>✔</td><td>Compounding</td><td></td><td>Non-contributory</td><td></td></tr>
<tr><th colspan="8">HERA CLASSIFICATIONS</th></tr>
<tr><td colspan="2">Task:</td><td colspan="6">Control room communications</td></tr>
<tr><td colspan="2">Information/ Equipment:</td><td colspan="6">Aircraft (on frequency) / R/T</td></tr>
<tr><td colspan="2">ET:</td><td colspan="6">Omission</td></tr>
<tr><td colspan="2">ED:</td><td colspan="6">Working Memory</td></tr>
<tr><td colspan="2">EM:</td><td colspan="6">Forget previous actions</td></tr>
</table>

HERA INCIDENT ANALYSIS FORM							
IP:	Unknown						
CC:	Cross-cultural R/T differences High/excessive R/T workload						
Reporter's assumptions:	N/A						
Analyst's assumptions:	N/A						
NOTES							
(i) The AIRPROX report states "The Sector controller, who was aware that the Support controller and the CSC were trying to bring the B767's level to her attention, believed that the aircraft was not on frequency, having no recollection of its first call". However, this led to an error of 'Judgement, Planning and Decision Making': IEM - Incorrect decision; PEM - Cognitive fixation.							
DESCRIPTION OF ERROR # 4							
The LUS sector controller's initial avoiding action heading for the B767 was not a good one because it was very similar to, or to the right of, the aircraft's track.							
How Detected:	Self, from radar display.						
How Recovered:	Instructed the B747 pilot to turn right, instructed the B767 pilot to descend and turn left.						
Causal		**Contributory**		**Compounding**	✔	**Non-contributory**	
HERA CLASSIFICATIONS							
Task:	RT communications/instructions, Planning, Radar monitoring						
Information/ Equipment:	Heading Avoiding action / radar						
ET:	Action too little Action too late						
ED:	Planning and Decision Making						
EM:	Misjudgement						
IP:	Unknown						
CC:	N/A						
Reporter's assumptions:	N/A						
Analyst's assumptions:	N/A						
NOTES							
N/A							
DESCRIPTION OF ERROR # 5							
The LUS sector controller assumed that by stating the aircraft's cleared level the B767 pilot would probably stop the climb, but she admitted that she should have used a more positive instruction to instruct the pilot to descend to FL280 or FL290							
How Detected:	Self, from radar display.						
How Recovered:	Instructed the B747 pilot to turn right, instructed the B767 pilot to descend and turn left.						
Causal		**Contributory**	✔	**Compounding**		**Non-contributory**	

HERA INCIDENT ANALYSIS FORM	
HERA CLASSIFICATIONS	
Task:	RT communications/instructions
Information/ Equipment:	Flight Level /radar/strip
ET:	Unclear information transmitted
ED:	Planning and Decision Making
EM:	Incorrect decision
IP:	Incorrect assumption
CC:	N/A
Reporter's assumptions:	N/A
Analyst's assumptions:	N/A
NOTES	
N/A	

Appendix C: The Air Traffic Control Team Safety Questionnaire

Air Traffic Control Team Safety Questionnaire

This questionnaire is part of a study aimed at understanding air traffic control team operational safety. You will greatly assist our research by completing this survey. **All data are strictly confidential**. Results will be presented only at the group level. No individual feedback will be given to management, so please be honest in your responses.

Please indicate how satisfied ***you*** are with each of the following aspects of ATC operations. Please answer by writing beside each item the letter from the scale below.

A	B	C	D	E
Very Unsatisfactory	**Unsatisfactory**	**Neutral**	**Satisfactory**	**Very Satisfactory**

☐ 1. Your own basic ATC training
☐ 2. Your own basic ATC instructor skills
☐ 3. Your own validation or recurrent training
☐ 4. Your own OJT instructor skills
☐ 5. Simulator training (if relevant)
☐ 6. Operation Manuals (including Standard Procedures)
☐ 7. Safety Manuals
☐ 8. Shift cycle
☐ 9. Shift schedule
☐ 10. Length of leave
☐ 11. My skills in handling normal operations
☐ 12. My skills in handling emergencies
☐ 13. Feedback on my daily operational performance

Please answer the following questions by ticking the box which best describes your opinion.

1. Automation reduces the requirement for team members to monitor the traffic situation closely.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

2. It is not my place to give pilots advice, other than airways information and clearance details.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

3. Team members share responsibility for prioritising activities in high workload situations.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

4. Effective team co-ordination requires controllers to take into account the personalities of other controllers.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

5. It is easier to make decisions when you first take over on an operating position.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

6. Asking for assistance makes one appear incompetent.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

Please answer the following questions by ticking the box which best describes your opinion.

7. To resolve conflicts, controllers should openly discuss their strategies with each other.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

8. It is easier to communicate with my own team than other teams and units.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

9. Trainees should not question senior team members' decisions.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

10. Flight crews never demand too much.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

11. Casual, social conversation in the operating environment during periods of low workload can improve team cohesion.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

12. It is important to avoid negative comments about the procedures and techniques of other controllers.

Strongly Disagree	**Slightly Disagree**	**Neutral**	**Slightly Agree**	**Strongly Agree**
☐	☐	☐	☐	☐

Please answer the following questions by ticking the box which best describes your opinion.

13. Discussing the traffic picture with other controllers helps to keep your own picture clearer.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

14. Good communication is as important as technical proficiency in the controlling environment.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

15. My unit would be capable of handling the situation if there was a system breakdown.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

16. I should maintain the traffic picture of the controllers I work with.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

17. Our training has prepared us to work as a well co-ordinated team in an emergency.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

18. Supervisors who encourage suggestions from team members are ineffective.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

Please answer the following questions by ticking the box which best describes your opinion.

19. I should inform those controllers who are affected by my plans and control actions and ask for their acknowledgement.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

20. Increased automation reduces the need for team communication.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

21. It is better to agree with other team members than to voice a different opinion.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

22. I perform as well with other units as with my own.

Strongly Disagree	Slightly Disagree	Neutral	Slightly Agree	Strongly Agree
☐	☐	☐	☐	☐

Years in ATC	________	Years in Tower	________	Male (M)	_____
Years in this ATC unit	________	Years in Approach	________	Female (F)	_____
		Years in Area Control Centre	________		

What is your present position in your ATC unit (you may tick more than one):

- ☐ Tower controller
- ☐ Approach controller
- ☐ Area controller
- ☐ Student
- ☐ Sector chief
- ☐ OJT-instructor
- ☐ Supervisor
- ☐ Other. Please specify: ____________

Where is your present unit: