



**MONASH** University  
Accident Research Centre

**HUMAN ERROR AND ROAD TRANSPORT:  
PHASE ONE – LITERATURE REVIEW**



**HUMAN ERROR AND ROAD TRANSPORT:  
PHASE ONE – LITERATURE REVIEW**

by

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**Abstract:**

Within complex, sociotechnical systems, human error has consistently been implicated as the major causal factor in a high proportion of accidents and incidents. For example, recent research within the road transport domain indicates that driver error contributes to as much as 75% of all roadway crashes. The present study represents the first phase of a research program of which the aim is to promote error tolerant intersections in Victoria and an error tolerant road transport system in Australia. The study involved a literature review of the human error-related research conducted to date in domains other than the road transport domain, a literature review of the human error-related research conducted to date within the road transport domain, and a review of contemporary error management approaches. The findings from this research indicate, amongst other things, that, compared to other domains in which human error has been identified as a major problem, there has been only a limited amount of human error-related research conducted to date within road transport; and that the development and application of error management programs has so far been virtually non-existent. Consequently, it was concluded that our knowledge and understanding of road user error and of its contributory factors is currently lacking. Further, it was concluded that the application of error management techniques within the Australian road transport system is a viable concept to pursue, which could potentially lead to significant enhancements in road user safety.

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**Key Words:**

Human Error, Road Safety Error, Transport Safety

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# Preface

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## Glossary

ACT	Australian Capital Territory
AEB	Accident Evolution and Barrier
AIMS	Australian Incident Monitoring Study
ANCIS	Australian National Crash In-Depth Study
ASR System	Aviation Self Reporting System
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATM	Air Traffic Management
BSMS	Boeing Safety Management System
CAA	Civil Aviation Authority
CAIR	Confidential Aviation Incident Reporting
CARS	Confidential Accident Reporting System
CDQ	Chinese Driving Questionnaire
CFIT	Controlled Flight into Terrain
CHIRP	Confidential Human Factors Incident Reporting Program
CIRS	Critical Incident Reporting System
CORE-DATA	Computerised Operator Reliability and Error Database
CPC	Common Performance Condition
CPIT	Cabin Procedural Investigation Tool
CREAM	Cognitive Reliability and Error Analysis Method
CRM	Crew Resource Management
DBQ	Driver Behaviour Questionnaire
DIRS	Driver Incident Reporting System
DREAM	Driver Reliability and Error Analysis Method
EEM	External Error Mode
EPC	Error Producing Condition
FAA	Federal Aviation Administration
FARS	Fatality Analysis and Reporting System
FICA	Factors Influencing the Causation of Incidents and Accidents

GEMS	Generic Error Modeling System
GFT	General Failure Type
HAZOP	Hazard and Operability Study
HEART	Human Error Assessment and Reduction Technique
HEI	Human Error Identification
HEIST	Human Error Identification in Systems Tool
HEP	Human Error Probability
HET	Human Error Template
HFACS	Human Factors Analysis and Classification System
HRA	Human Reliability Analysis
HSIS	Highway Safety Information System
HTA	Hierarchical Task Analysis
IAM	Institute of Aviation Medicine
ICAM	Incident Cause Analysis Method
IEM	Internal Error Mode
JHEDI	Justification of Human Error Data Identification
MARS	Major Accident Reporting System
MEDA	Maintenance Error Decision Aid
MESH	Managing Engineering Safety Health
MORT	Management and Oversight Risk Tree
MTO	Man, Technology and Organisation
MUARC	Monash University Accident Research Centre
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
OECD	Organisation for Economic Co-operation and Development
OTS	On-The-Spot
PSA	Probabilistic Safety Assessment
PSF	Performance Shaping Factors
PEAT	Procedural Event Analysis Tool
PF	Pilot Flying
PEM	Psychological Error Mechanism
PNF	Pilot Not Flying



REDA	Ramp Error Decision Aid
RPF	Railway Problem Factors
SCAT	Systematic Cause Analysis Technique
SDP	State Data Program
SHEL	Software, Hardware, Environment and Liveware
SHERPA	Systematic Human Error Reduction and Prediction Approach
SMARTER	Specific, Measurable, Accountable, Reasonable, Timely, Effective and Reviewed
SRK	Skill, Rule, and Knowledge
STEP	Sequential Timed Events Plotting
TRACER	Technique for the Retrospective and Predictive Analysis of Cognitive Errors
THERP	Technique for Human Error Rate Prediction
4WD	Four wheel Drive

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# Executive Summary

## Background and Overall Objective

Human error is a problem of great concern within complex sociotechnical systems and has consistently been implicated in a high proportion of accidents and incidents. Recent research within the road transport domain indicates that human error contributes to as much as 75% of all roadway crashes (Hankey, Wierwille, Cannell, Kieliszewski, Medina, Dingus & Cooper, 1999; cited in Medina, Lee, Wierwille & Hanowski, 2004). Despite this, the application of traditional error management programs within the road transport domain has been only minimal. Relatively little is currently known regarding the contributory factors, nature and consequences of the different errors that are made by road users.

The ATSB and Monash University Accident Research Centre (MUARC) Baseline Research Program commissioned MUARC to investigate the construct of human error within the Australian road transport system in general (ATSB), and at intersections in Victoria (Baseline), with a view to promoting an error tolerant road transport system in Australia and error tolerant intersections in Victoria. This literature review represents the first stage of the research program, and was partitioned into three phases: a review of the human error-related research conducted to date in domains other than road transport; a review of the current theoretical and methodological approaches to human error management in those domains; and a review of the human error-related research conducted to date within the road transport domain.

## Defining Human Error

The first phase of this research involved a review of the human error-related research conducted to date in domains other than road transport. There have been numerous attempts at defining the construct of human error but no universally accepted definition exists. Of those definitions available, the most appropriate in relation to this research are the definitions proposed by Senders and Moray (1991), and Reason (1990). Senders and Moray (1991) suggested that error is something that has been done which was either:

- not intended by the actor;
- not desired by a set of rules or an external observer; or
- that led the task or system outside of its acceptable limits.

Reason (1990) defined human error as, “a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency.” (Reason, 1990).

Human error can therefore be generally defined as any mental or physical activity, or failure to perform activity, that leads to either an undesired or unacceptable outcome.

## **Error Classification**

Error classification is used to identify and classify the different types of errors that humans make. There are a number of different classification schemes or taxonomies available. The most common was the slips and lapses, mistakes and violations classification proposed by Reason (1990). Slips are the most common form of human error, and are categorised as those errors in which the intention or plan was correct but the execution of the required action was incorrect. Lapses refer to more covert error forms that involve a failure of memory that may not manifest itself in actual behaviour (Reason, 1990). Lapses typically involve a failure to perform an intended action or forgetting the next action required in a particular sequence. Mistakes reside in the unobservable plans and intentions that are formed by an operator. A mistake is categorised as an inappropriate intention or wrong decision followed by the correct execution of the required action. A mistake occurs when an actor intentionally performs an action that is either inappropriate or unrequired. Violations are categorised as any behaviour that deviates from accepted procedures, standards and rules. Violations can be either deliberate or unintentional. Deliberate violations occur when an operator deliberately deviates from a set rules or procedures, and unintentional violations occur when an operator unintentionally deviates from a set of rules or procedures.

In addition to the slips and lapses, mistakes and violations classification scheme, a number of more complex domain-specific error classification schemes and taxonomies were also identified, including various error taxonomies used for accident analysis and investigation, human error identification (HEI), human reliability analysis (HRA) and probabilistic safety assessment (PSA). These included error taxonomies from the technique for human error rate prediction (THERP), the systematic human error reduction and prediction approach (SHERPA) and the cognitive reliability and error analysis method (CREAM).

## **Theoretical Perspectives on Human Error**

Two theoretical perspectives or approaches to human error in complex, sociotechnical systems were identified. These are the person approach and the systems perspective approach.

### **The Person Approach**

The person approach focuses upon the identification and classification of the errors that operators make at the so-called 'sharp-end' of system operation (Reason, 2000), and seeks to identify the internal or psychological factors (e.g. inattention, loss of vigilance and carelessness) involved in error occurrence. According to the person approach errors arise from aberrant mental processes such as forgetfulness, inattention, poor motivation, carelessness, negligence, and recklessness (Reason, 2000). Person approach-related research typically attempts to identify the nature and frequency of the errors made by operators within complex systems, the ultimate aim being to propose strategies, remedial measures and countermeasures designed to prevent future error occurrence. When using the person approach, human error is treated as the cause of most accidents; the systems in which people work are assumed to be safe; human unreliability is seen as the main threat to system safety; and safety progress is achieved by protecting systems from human unreliability through automation, training, discipline, selection and proceduralisation (Dekker, 2000). A number of different person-based models of human error have been proposed,

including the skill, rule and knowledge-based framework (SRK; Rasmussen, 1983; cited in Vicente, 1999), the generic error modelling system (GEMS; 1990) and Rasmussen's model of human malfunction (Rasmussen, 1982). It was concluded that there are a number of disadvantages associated with the person-based approach to error in safety critical systems; namely the blame culture that they promote and the fact that subsequent error countermeasures are aimed entirely at the individual, with system wide failures being, to a large extent, ignored.

## **The Systems Perspective Approach**

The systems perspective approach treats error as a systems failure, rather than an individual operator's failure and considers the combined role of latent conditions (e.g. inadequate equipment, poor designs, inadequate supervision, manufacturing defects, maintenance failures, inadequate training, clumsy automation, inappropriate or ill-defined procedures) and human errors (also known as active errors or failures) in accident causation. Human error is no longer treated as the primary cause of incidents and accidents; rather it is seen to be a consequence of the latent conditions residing within the system. It is a combination of latent conditions and operator errors that result in incidents and accidents. Therefore, when using the systems approach, human error is treated as a symptom of problems within the system, it is assumed that safety is not inherent within systems, and that human error is linked to the tools used, tasks performed and operating environment (Dekker, 2002). The systems perspective model of human error and accident causation in complex systems proposed by Reason (1990) is the most influential and widely recognized of the various systems approaches to error, and indeed of all human error models available in the literature. The systems perspective model considers the interaction between latent conditions and errors and their contribution to organisational accidents. According to the model, complex sociotechnical systems comprise various organisational levels that contribute to the production of system outputs (e.g. decision makers, line management, productive activities and defences). At each of the levels within the system, various defence layers exist which are designed to inhibit the occurrence of occupational accidents. Examples of defences include protective equipment, rules and regulations, training, checklists and engineered safety features. Holes or weaknesses in these defences, created by latent conditions and errors, create 'windows of opportunity' for accident trajectories to breach the defences and cause an accident. According to the systems perspective, organisational accidents occur when the holes in the systems defences line up in a way that allows the accident trajectory to breach each of the different defence layers. Latent conditions and errors combine in such a way that the accident is 'allowed' to happen. On most occasions, accident trajectories are halted by defences at the various levels in the system. However, on rare occasions, the holes or windows of opportunity line up to allow the accident trajectory to breach all of the systems defences, culminating in an accident or catastrophe.

Other systems perspective-based models of error were also identified in the literature, including the SHELL model (Edwards, 1988; cited in Wiegmann & Shappell, 2003) and Moray's (1994; cited in Strauch, 2005) systems perspective model of error in complex systems. It was concluded that the systems perspective model proposed by Reason (1990) is currently the dominant model of human error within the literature and also that the systems perspective approach is the most appropriate for error management in complex, sociotechnical systems.

The human error-related research conducted to date in complex, dynamic domains was broadly classified as either person approach-related research or systems approach-related research. It was concluded that the majority of initial human error-related research can be broadly categorised as person-based. However, in recent times the focus has shifted from the person approach to the systems perspective approach, and the systems perspective is currently receiving increased attention in most safety-critical domains. It was also concluded, however, that, despite the recent increase in systems based research, the dominant view on human error in a number of safety-critical domains, including road transport, is still the person-based view; and that this is detrimental to safety and error management, as countermeasures are aimed at the individual, ignoring the various latent conditions that may reside within a particular system.

## **Error Management**

The next phase of this research involved a review of the approaches currently used for error management in complex sociotechnical systems (i.e. systems composed of technical, psychological and social elements). Error management programs use formal methods to help develop a deeper understanding of the nature of, and factors surrounding, error occurrence in a particular system. The ultimate goal of error management programs is the eradication, reduction, management and mitigation of errors and their associated consequences. A review of those error management-related approaches that could potentially be implemented within the road transport domain was conducted. The review also covered error data collection and error management-related techniques. The review indicated that error management programs of some form or other are employed in most safety critical domains. The literature review also indicated that there is a plethora of different error management related approaches, techniques and methodologies available. For example, Reason (1997) cited a wide range of error management-related techniques, including selection, training, licensing and certification, skill checks, human resource management, quality monitoring and auditing, technical safety audits, unsafe act auditing, hazard management systems, procedures, checklists, rules and regulations, administrative controls, total quality management, probabilistic safety assessment, human reliability analysis, human error identification, and crew resource management. Those error management-related techniques that were deemed the most applicable to the road transport system were reviewed in depth. A summary of the techniques, methods and approaches discussed is presented below:

- **Accident Investigation and Analysis.** Retrospective accident analysis and investigation involves the use of structured techniques to identify the human and system contributions to accidents. According to the literature, there are various accident analysis techniques available, such as HFACS, ICAMS, fault tree analysis, AcciMaps, and TRACER. It was concluded that accident analysis is attractive for a number of reasons: it exposes investigators to the entire sequence of events, including triggering conditions, and outcome; it permits the identification of the human and systemic causal factors involved in a particular accident and also the identification of system failures or latent conditions, such as bad design, inadequate training, inadequate equipment and poor management; and it aids the development of countermeasures designed to prevent similar accidents occurring in the future. It was also concluded, however, that accident analysis approaches are beset by a number of problems, including the apportioning of blame to individuals, and the various problems associated with hindsight.

- **Incident Reporting Systems.** Incident reporting systems are used to collect pertinent information regarding critical incidents (or near misses), error, safety compromising incidents and safety concerns within complex, dynamic systems. Incident reporting systems are now common in most safety critical domains, including the aviation domain (e.g. ASRS), the healthcare domain (e.g. MedWatch) and nuclear power domains (e.g. MARS). It was concluded that the utility of such systems lies in their ability to generate large amounts of incident or near miss data that would otherwise go un-noticed or unreported. Incident reporting systems work on the premise that these near misses are indicators of accidents waiting to happen, and so preventative measures can be taken before accidents occur. The data obtained is useful as it can be used to identify the types of errors made, the causes of the errors made, and also recovery strategies for the errors made in a particular system. Despite the various advantages associated with the collection of near miss data and the use of incident reporting systems, it was also concluded that there are a number of disadvantages that may affect the data collected. These included reluctance by system personnel to report such incidents due to a number of reasons, a perceived worthlessness and skepticism of such schemes, problems relating to the accuracy of incident descriptions, the high cost associated with running such schemes, and the various biases that incident report data are subject to.
- **Human Error Identification.** HEI techniques are used to predict potential human or operator error in complex, dynamic systems. A number of different types of HEI approach were identified, including taxonomy based techniques, error identifier techniques, error quantification techniques, cognitive modeling techniques and cognitive simulation techniques. HEI techniques have previously been employed in a number of different domains, including the Nuclear power and petro-chemical processing industry (Kirwan, 1996), air traffic control (Shorrock & Kirwan, 2002), aviation (Marshall et al, 2003), naval operations, military systems, space operations (Nelson et al, 1998), medicine and public technology (Baber & Stanton, 1996). The utility of HEI techniques lies in their ability to identify potential errors before they occur, allowing pro-active remedial measures to be taken. This also allows them to be applied early in the design process, before an operational system actually exists. It was also concluded, however, that HEI techniques suffer from a number of problems, including issues regarding reliability and validity. For example, different analysts, with different experience, may make different error predictions for the same task (inter-analyst reliability). Similarly, the same analyst may make different judgements on different occasions (intra-analyst reliability).
- **Training.** Training is also typically used as a part of error management in complex, dynamic systems. Traditionally, retraining operators was the most common response to continued error occurrence in complex, dynamic domains, and novel training interventions and retraining were used to try and reduce error occurrence in such systems. As a result of the literature review, the concept of error management training was identified. Error management training is a form of crew resource management (CRM) training that attempts to provide operators with the skills (technical and non-technical) to detect and manage errors as and when they arise.
- **Error Databases.** The culmination of error-related data collection in complex, dynamic domains is typically the development of an error database. Error databases are used for a number of purposes, including for in-depth studies, the identification of different error trends, quantitative error analysis and to inform the development of error countermeasures.

- **Traditional Data Collection Techniques.** A number of traditional data collection techniques have also been used in the past to collect error-related data in complex, sociotechnical systems, including observational study, interviews and questionnaires. Such approaches are attractive as they offer a simplistic means for collecting error-related data, typically incur a low cost and can be used to collect large volumes of error data.
- **Specific Error Management Techniques.** A number of approaches have also been developed specifically for error management purposes in safety-critical domains. Techniques such as TRIPOD DELTA, REVIEW and MESH are used to manage error within their respective domains. Such approaches work by identifying the extent to which error causing conditions are a problem for concern, and inform the development of countermeasures designed to reduce error causing or latent conditions.
- **General Error Management Techniques.** Other, more general, approaches to error management within complex, sociotechnical systems were identified, including procedures, checklists, system redesign, awareness campaigns and the introduction of novel technology and artifacts.

A number of key aspects of error management should be considered when designing and implementing error management programs:

- the effectiveness of error management programs appears to be entirely dependent upon the collection and analysis of accurate data regarding the nature of, and contributory factors associated with, errors and latent failures within the system in question. The error data collected is key to identifying and understanding the errors and causal factors involved, and also to the development of strategies and countermeasures designed to manage, eradicate or tolerate error occurrence;
- regardless of experience, skill-level, technological support, training and other factors, errors are consistently, and always will be, made by operators within complex systems;
- error management should recognise that the errors made by operators within the system may be a consequence of latent conditions residing throughout the system; and
- error management should recognise that accident causation in complex, dynamic systems typically involves a combination of latent conditions residing within the system and also errors committed by operators performing activity within the system.

The literature review also yielded a number of general conclusions regarding error management in safety-critical domains:

- error management programs have been implemented in a number of different domains, including civil aviation, medicine, nuclear power and rail;
- error management programs are used to better understand the nature of errors and latent conditions within systems, identify and develop countermeasures, procedures and behaviours that might lead to the mitigation of these errors and latent conditions, and promote error tolerance within systems;
- most error management programs adopt a systems, rather than a person or individualistic, approach to error within complex systems, considering the combined role of latent conditions and errors in accident causation;



- most error management programs are based upon an acceptance that humans make errors, and focus on the development of error tolerance within systems rather than the eradication of error;
- there are numerous error management-related techniques available, including incident reporting systems (e.g. ASRS), accident investigation tools (e.g. HFACS), human error identification techniques (e.g. SHERPA), and error management training programs (e.g. CRM);
- error management programs normally employ a mixture of the error management-related techniques available, and the techniques used are dependent upon the domain in which the program is implemented;
- error management programs depend upon the collection of accurate data regarding the nature of, and contributory causes associated with, errors in complex, dynamic systems;
- the success or effectiveness of error management programs is difficult to measure or quantify;
- there have been only limited attempts to implement error management programs in the road transport domain worldwide.

## **Human Error and Road Transport**

The next phase of this research involved a review of the human error-related research conducted to date in the road transport domain. The aim of the literature review was to determine what is currently known regarding human error in the road transport domain. Compared to other domains in which human error has been identified as a problem, there has been only a limited amount of human error-related research conducted within the road transport domain. Using the person and systems perspective approach dichotomy described previously, it was concluded that the majority of research conducted to date within the road transport domain has been conducted from a person-based perspective on human error. That is, the majority of the research published in the open literature has attempted to identify and classify the nature and frequency of the errors made by drivers and also the person-based causal factors that contributed to these errors. For example, a large portion of the research conducted to date has involved the use of the Driver Behaviour Questionnaire (DBQ) developed by Reason, et al (1990) to identify the different types of driver error made by different driver groups. Further, the literature review indicated that research into the different types of errors made by elderly drivers also represents a large portion of the research reported in the literature.

The systems perspective approach has received only limited attention to date, but systems perspective based research in the road transport domain has increased in recent years, and it is apparent that the relevant research communities are beginning to adopt a systems perspective on human error within the road transport domain. For example, Wierwille, Hanowski, Hankey, Kieliszewski, Lee, Medina, Keisler & Dingus (2002) described a comprehensive study that was conducted at the Virginia Tech Transportation Institute in order to investigate the nature and causes of driver errors and their role in crash causation, to develop driver error taxonomies and also to develop recommendations for improvements in traffic control devices, roadway delineations and accident reporting forms. Amongst other things, a crash-contributing factors taxonomy was developed. According to the taxonomy, there are four different groups of factors

that contribute to task performance problems that occur during crashes: inadequate knowledge, training and skill; impairment; wilful behaviour; and infrastructure and environment.

Significantly, of the human error-related research conducted to date in the road transport domain, the literature indicated that there have been no attempts to use mass accident and incident data to determine the different types of errors made by road users and their associated causes. Consequently, there is currently only limited information available regarding the different errors made by road users and the contribution of system wide latent conditions to error occurrence. It was concluded that this represents a significant gap in our knowledge of error in the road transport domain. As alluded to previously, it was concluded that the understanding and management of error in complex, dynamic systems requires the provision of structured methods that can be used for the collection of pertinent error-related data and there is currently a lack of such approaches developed specifically for use in the road transport domain. The collection of appropriate error-related information is consequently lacking and there is scope for much further research into the construct, particularly with regards to systems perspective-related research and the development of structured error-related data collection techniques.

## **Road Transport Risk Management Paradigms**

A review of existing road transport risk management paradigms was also conducted during this phase of the research. The Swedish Vision Zero and Dutch Sustainable Safer Systems approaches were identified as those that currently adopt a systems perspective approach to error, acknowledge the fallibility of road users, and aim to promote error tolerance within their respective road systems. The current Australian road safety approach was also reviewed. It was concluded that the Australian national road safety plan, despite initially adopting a person-based approach to driver error, has recently moved to adopt more systems-perspective type approach to road user error. For example, the Australian Transport Council presented a National Road Safety Action plan for 2005 and 2006 which included the Safe System concept, a new framework for enhancing road safety in Australia. Within this framework, a marked move towards human error tolerance within the road system is evident. It was therefore concluded that the Safe System Framework represents a significant shift towards the systems perspective and error tolerance-related principles adopted by the Vision Zero and Dutch Sustainably Safe Systems approaches.

From the review of current road transport-related human error research and risk management programs, it was concluded that there is currently only limited attention given to error management within the Australian road transport system. The lack of error management approaches employed within the Australian road transport system led us to conclude that our current knowledge of road user error and of the latent conditions that contribute to road user error is limited. Additionally, a large amount of error-related data is currently unobtainable due to there being no means by which to collect such data (e.g. error-focused accident and incident reporting). We currently do not, and cannot, fully understand the nature of the system-wide latent failures that exist within the road transport system, their role in error occurrence and also the nature and consequence of the errors made by different road users. It was also concluded that a framework for error tolerance within the Australian road transport domain should provide both the techniques required for the collection of latent failure and error-related data, and also the techniques required for the analysis of error-related data.

## Conclusions

Previous research has indicated that human error is a causal factor in approximately 75% of all road transport accidents. Despite this, the literature review indicated that there has been only a paucity of human error-related research conducted in road transport to date. Consequently, very little is currently known about the different errors that road users make, or about the conditions within the road transport system that contribute to these errors being made. In addition, the use of error management approaches within road transport systems worldwide has previously been largely neglected. In Australia, there is an increasing recognition of the need to make the road system more tolerant of road user error, yet there are currently no programs in place to contribute to the identification and understanding of road user error, its causes, recovery strategies, and its role in accidents and incidents. As a result of this, we currently do not know to what extent human error contributes to road traffic accidents and incidents in Australia. However, converging evidence from overseas suggests that it is likely to be a significant issue.

Of the error management approaches that have been used previously in other complex sociotechnical systems, it was concluded that a number could potentially be used within the Australian road transport system as part of an error management program. These applicable error management-related techniques include error and latent condition classification schemes, specific error management techniques, accident investigation and analysis, incident reporting systems, human error identification techniques, error management training and error databases. Finally, it was concluded there is great scope for further research on the construct of human error within road transport and that further investigation into the development and validation of the techniques required for this purpose should be made.

## Recommendations for Further Research

As a result of this study, a number of pertinent areas of future research were identified. In particular, further research into the means with which to collect and analyse human error-related data and into the application of error management approaches within road transport is required. The recommendations for further research are summarised below:

- the development of a model of road user error;
- development of prototype road user error and latent condition classification schemes;
- the design and conduct of a pilot study designed to collect data on errors and latent conditions at intersections;
- development of an error-data collection-oriented approach to road transport accident reporting and analysis;
- development of a road transport specific incident or near-miss reporting system;
- development of a road transport specific Human Error Identification (HEI) technique;
- investigation and development of error management training interventions;
- development of a road transport-specific error management technique.; and
- development and implementation of strategies designed to increase error tolerance at intersections and within the Australian road transport domain in general.

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## Chapter 1 Introduction

The aim of the research described in this report was to review the literature surrounding the construct of human error, with a view to identifying potential human error management-related applications that could be used to aid the development of error tolerant intersections in Victoria and an error tolerant road transport system in Australia. Human error, in some form or another, has consistently been implicated as the major cause of accidents and incidents in complex, sociotechnical systems. For example, within the road transport domain, recent research has indicated that human or driver error may contribute to as much as 75% of all roadway crashes (Hankey, Wierwille, Cannell, Kieliszewski, Medina, Dingus & Cooper, 1999; cited in Medina, Lee, Wierwille & Hanowski, 2004). It has also been previously estimated that human actions are a sole or contributory factor in as much as 95% of traffic crashes (Rumar, 1985; cited in Aberg & Rimmo, 1998). Despite these estimates, it is apparent that, in contrast to other domains in which human error has been identified as a major problem, the construct has previously received only limited attention within the road transport domain.

Further, of the research that has been conducted in the road transport domain, the majority has focussed on the identification and classification of the different errors made by different driver groups (e.g. elderly, young, novice, etc). Consequently, relatively little is known about the different features of the road transport system that contribute to the occurrence of these errors, and of the associated consequences, recovery, mitigation and management of these errors. This is in contrast to other domains where, due to recent developments in human error theory, contemporary human error research and management has taken a *systems perspective* approach to error and accident causation. Rather than focusing entirely upon errors made at the so-called ‘sharp-end’ of system operation (i.e. by individual operators), systems perspective approaches also consider the presence of error-causing or latent conditions residing within systems that lead to the errors made by individual operators. Instead of treating error as the primary *cause* of accidents and incidents, error is seen as a *consequence* of the latent conditions residing within the system. Taking this perspective, road user error is treated as a consequence of the various latent or error causing conditions (e.g. poor vehicle interface design, inadequate road signage, poor road infrastructure design, inadequate training & equipment etc) residing within the road transport system.

One of the features of systems perspective approaches is that, rather than attempting to eradicate error completely, they accept that errors occur and attempt to promote error tolerance throughout the system in question. The present research was undertaken with a view to developing a framework for error tolerant intersections in Victoria and an error tolerant road transport system in Australia. The main aims of the research were to review what is currently known about human error in other domains and also the current approaches to human error management in those domains, review the limited human error-related research that has been conducted to date in the road transport domain, and review the different error management approaches that have previously been applied in complex sociotechnical systems.

## 1.1 Research Activities

The research described in this report comprised three key phases. A summary of each phase is given below.

1. Human error literature review. A review of the human error-related literature was conducted to identify and understand the nature of human error related research that has been conducted to date in domains other than the road transport domain. The literature review covered definitions of human error, major theories and models of human error, different error classification schemes and taxonomies, and current and emerging developments in human error research across different domains.
2. A review of error management in complex, sociotechnical systems. A review of the current approaches to error management in complex, sociotechnical systems was conducted in order to determine and better understand the techniques that are currently used for error management purposes. The review included human error related risk management programs in other domains and also other human error-related methodologies.
3. A review of human error-related research undertaken in the road transport domain. A review of the human error-related research conducted to date within the road transport domain was conducted to identify and understand the nature of the human error-related research conducted to date and also to determine the current understanding of the construct within road transport. The literature review included a review of the human error-related research that has been conducted to date in the road transport domain, a review of contemporary human error-related road transport risk management programs worldwide, and a review of the current approach to road transport risk management in Australia.

This report describes the work conducted during each of the research phases identified above, and presents the key findings from each. The literature review of human error related research is presented in chapter 2, and the concept of error management is discussed in chapter 3. In chapter 4, the results of the literature review of human error-related research and risk management programs in the road transport domain is presented. Finally, the conclusions derived from this research are presented in chapter 5.



## Chapter 2 Human Error

### 2.1 Introduction to Human Error

The construct of human error is an area of great importance to the human factors and psychological practitioner, particularly within complex, sociotechnical systems. Within such domains, human error has consistently been identified as at least a contributory factor in a high proportion of accidents and incidents. For example, recent research indicates that human or pilot error is the source of up to 70% of incidents occurring in the commercial aviation domain (BASE, 1997; cited in McFadden & Towell, 1999). Within the rail transport domain, human error was identified as a contributory cause of almost half of all collisions occurring on UK Network Rail between 2002 and 2003 (Lawton and Ward, 2005). Within the health care domain, the US Institute of Medicine estimates that between 44,000 and 88,000 people die each year as a result of medical errors (Helmreich, 2000) and it has also been estimated that inappropriate human actions are involved in as much as 95% of road traffic crashes (Rumar, 1995; cited in Aberg & Rimmo, 1998).

Additionally, over the past four decades, human error has been implicated in a number of high profile, high casualty catastrophes, including the three mile island, Chernobyl and Bhopal nuclear power disasters, the Tenerife, Mont St Odile, Papa India and Kegworth air disasters, the Herald of Free Enterprise ferry disaster, the Kings Cross fire disaster, the Ladbroke Grove rail disaster and many others. Consequently, the construct has received considerable attention, not only from the relevant academic and research communities, but also from the general public, and has been investigated across a wide range of domains, including military and civil aviation (Shappell & Wiegmann, 2000; Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann & Dekker, 2003), aviation maintenance (Rankin, Hibit, Allen & Sargent, 2000), rail (Lawton & Ward, 2005), road transport (Reason, Manstead, Stradd, Baxter and Campbell, 1990), nuclear power and petrochemical reprocessing (Kirwan, 1992a, 1992b, 1998a, 1998b, 1996), military, medicine (Helmreich, 2000), air traffic control (Shorrock and Kirwan, 2002), and even the space travel domain (Nelson, Haney, Ostrom, & Richards, 1998).

The first phase of this research involved a review of the human error-related research that has been conducted to date in domains other than the road transport domain. The review was conducted in order to develop a comprehensive understanding of the construct and also to identify the different types of human error management approaches and methodologies that have been used in the past. The literature review was based upon a survey of standard human factors and ergonomics and human factors textbooks, relevant scientific journals, existing human error-related research reports and also relevant internet sources. The results of the literature review are presented in the following chapter.

## 2.2 Defining Human Error

Human error is an extremely common phenomenon and people, regardless of ability, skill level and expertise, make errors everyday. Pulling a door when it requires pushing, locking one's car keys in the car, pressing the wrong pre-set button on the car stereo, choosing the wrong exit on a roundabout, pressing the wrong key on the computer keyboard and forgetting to post a letter are all examples of the common, everyday errors that people make. The typical end result of error occurrence is a failure to achieve a desired outcome or the production of an undesirable outcome. Most of the everyday errors that people make have only a minimal impact that can be quickly recovered. However, when the same kinds of errors are made in complex sociotechnical systems, the consequences can be much greater, and such errors can potentially lead to accidents and incidents involving injury and fatalities.

At its simplest, human error can be defined as the performance of an incorrect or inappropriate action, or a failure to perform a particular action. Although this definition seems extremely simplistic, the construct is not as straightforward as it first appears, and a great amount of research has been conducted in order to better understand the phenomenon. Different error definitions, categories, classification schemes, theories, and models have all been developed in order to contribute to our understanding of human error. As a starting point to this report, it is useful first of all to present an appropriate definition of the construct. According to the literature, there have been numerous attempts at defining human error. However, a universally accepted definition of human error does not yet exist. Rasmussen (1982) points out the difficulty in providing a satisfactory definition of human error, and some researchers have even suggested that human errors do not in fact exist (Taylor, 1987; cited in Fuller, 1990). A brief summary of the more prominent definitions offered in the literature is presented below.

Rasmussen (1987; cited in Fuller, 1990) suggests that human error represents a mismatch between the demands of an operational system and what the human operator does. Rasmussen, Duncan & Leplat (1987; cited in Lourens, 1989) defined human error as an act that is counterproductive with respect to the persons (private or subjective) intentions or goals. Senders and Moray (1991) suggest that a generally accepted definition of error is something that has been done which was either:

- not intended by the actor;
- not desired by a set of rules or an external observer; or
- that led the task or system outside of its acceptable limits.

Woods, Johannesen, Cook & Sarter (2004; cited in Strauch, 2005) define error as “a specific variety of human performance that is so clearly and significantly sub-standard and flawed when viewed in retrospect that there is no doubt that it should have been viewed by the practitioner as sub-standard at the time the act was committed or omitted”. Hollnagel (1993; cited in Strauch, 2002) labels errors as ‘*erroneous actions*’ and defines them as “an action which fails to produce the expected result and which therefore leads to an unwanted consequence”. Probably the most widely recognised definition of human error is offered by Reason (1990), who formally defines human error as,

*“A generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency.”* (Reason, 1990)

Taking the definitions proposed above together, human error can be defined as any mental or physical activity, or failure to perform activity, that leads to either an undesired or unacceptable outcome.

According to Kirwan (1998a) there are three major components to an error. These are the external error mode (EEM), performance shaping factors (PSF), and the psychological error mechanism (PEM). The EEM refers to the external manifestation of the error, or the form that the error takes in the world (e.g. pressed wrong button or failed to check display reading). PSFs refer to those factors which influence the likelihood of the error occurring (e.g. environmental conditions, inadequate training, poor interface design, time pressure etc). The PEM refers to the 'internal' manifestation of error or how the actor failed psychologically (e.g. memory failure). Whilst a generic definition of human error is useful in that it identifies what it is that actually constitutes a human error of some sort, it is the different types or kinds of errors that are made by operators within complex systems that are of greater interest to human factors and psychology professionals. Past research has led to the identification and classification of a myriad of different error types within the general category of human error, and various error classification schemes or taxonomies have been proposed. In the following section, an overview of the different classifications of error types proposed in the literature is presented.

## **2.3 Error Classification**

Error classification is used to identify and classify the different types of error that humans make. Previous research has led to the identification and classification of various different types or forms of error. At its simplest, error classification involves the use of simplistic error type classification schemes to classify different errors. In more complex, organisational environments, such as the nuclear power and aviation domains, more sophisticated taxonomies of different error types linked to PSF taxonomies and PEM taxonomies are used. An overview of the different error classifications and taxonomies proposed in the literature is presented in the following section.

At the most basic level of error classification, a distinction between errors of omission and errors of commission is proposed. Errors of omission are those instances where an actor fails to act at all, such as failing or forgetting to perform a particular action. Errors of commission are those instances where an actor performs an action either incorrectly or at the wrong time, such as pressing the wrong button, performing the required action at the wrong time in a sequence or performing an action too early or too late.

Payne and Altman (1962; cited in Isaac, Shorrock, Kennedy, Kirwan, Anderson & Bove, 2002) proposed a simplistic information-processing theory based error classification scheme containing the following categories of error:

1. Input errors – those errors that occur during the input sensory and perceptual processes e.g. visual perception and auditory errors;
2. Mediation errors – those errors that occur or are associated with the cognitive processes employed between the perception and action stages; and
3. Output errors – those errors that occur during the selection and execution of physical responses.

The most commonly referred to error classification within the literature, however, is the slips and lapses, mistakes and violations classification proposed by Reason (1990), an overview of which is presented below.

## Slips and lapses

The most common form of human errors is slip-based errors. Slips can be categorised as those errors in which the intention or plan was correct but the execution of the required action was incorrect. In the driving context, an example of a slip would be when a driver who plans to push the brake pedal to slow down inadvertently pushes the accelerator pedal or when a driver intending to signal to take the next turning off the freeway turns on the windshield wipers instead of the side-indicators. In both cases the intention (i.e. to push the brake or turn on the relevant indicator) was correct, but the physical execution of the required action was incorrect (i.e. pushing the accelerator pedal instead of the brake pedal or moving the windshield wiper stalk instead of moving the indicator stalk). Slips are therefore categorised as actions with the appropriate intention followed by the incorrect execution, and are also labelled action execution failures (Reason, 1990). Within the slips error category, Norman (2001) distinguishes between five different forms of slip-based errors. These are *capture errors*, *description errors*, *data-driven errors*, *associative activation errors* and *loss of activation errors*. A brief description of each slip-based error is given below:

- *Capture errors*. A capture error occurs when a frequently conducted activity overrides or ‘captures’ the intended activity. A frequently cited example of a capture error is when a person attempts to drive to the local shops but ends up driving to work instead. In this case, the frequently conducted activity of driving to the workplace (which is similar to the intended activity) overrides the intended activity of driving to the local shops.
- *Description errors*. A description error occurs when the intended action is very similar to other alternative actions. An example of a typical description error would be when a person attempts to put a box of breakfast cereal back in the pantry but instead places it in the fridge. The intended action of placing the box of cereal in the cupboard is very similar to placing an object in the fridge, and so the latter action is performed.
- *Data-driven errors*. Data-driven errors occur when sensory data intrudes on an operator’s action sequence and causes unintended behaviour. An example of a data-driven error would be when a person is typing a letter and talking at the same time, and begins to type words from the conversation instead of the intended letter content.
- *Associative activation errors*. While data-driven errors are caused by external data, associative activation errors are caused by internal data (i.e. thoughts and ideas). A common example of an associative activation error is when a person is thinking of something other than the topic that they are writing about, and they inadvertently begin to write about the topic that they are thinking about.
- *Loss of activation errors*. Loss of activation errors occur when a person embarks on a task or action but then forgets why. One example of a loss of activation error would be when a person begins to walk to a location but, on arriving, cannot remember why they have come to be there.

- *Mode errors.* Mode errors involve artifacts that have different operating modes. A very simple example of a mode error would be when an operator assumes that they are operating a system in one mode, but they are actually operating the system in another mode. Mode errors are especially common in systems that have dual functionality control devices. A mode error was implicated in the Mont St Odile disaster in 1992, which involved an A320-111 Airbus commercial aircraft impacting into the side of a mountain in Strasbourg, claiming the lives of 87 people. The crash was attributed to pilot error caused by a faulty design which led the flight crew to inadvertently select a 3,300 feet per minute descent rate instead of the required 3.3° flight path angle on the approach to Strasbourg airport. Instead of operating in the required flight path angle mode, the flight crew was actually operating in vertical speed mode.

Whilst slip-based errors are observable errors involving an incorrect execution of a correct plan, lapse-based errors refer to more covert error forms that involve a failure of memory that may not manifest itself in actual behaviour (Reason, 1990). Lapses typically involve a failure to perform an intended action or forgetting the next action required in a particular sequence. Examples of lapses include a person forgetting to turn off the lights when departing their car, even though they fully intended to do so and also forgetting to lock their car even though they fully intended to do so. Whilst slips occur at the execution stage, lapses occur at the storage stage, whereby intended actions are formulated prior to the execution stage of performing them. Reason (1990) proposes the following definition of slips and lapses:

*“Slips and lapses are errors which result from some failure in the execution and/or storage stage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective.”* (Reason, 1990)

## **Mistakes**

Whilst slips reside in the observable actions committed by operators, mistakes reside in the unobservable plans and intentions that are formed by an operator. A mistake is therefore categorised as an inappropriate intention or wrong decision followed by the correct execution of the required action. A mistake occurs when an actor intentionally performs a wrong action. Therefore mistakes originate at the planning level, rather than the execution level, and can also be termed planning failures (Reason 1990). For example, a mistake would be when a driver decides to accelerate when the appropriate action would have been to brake or slow down. According to Reason (1990) mistakes involve a mismatch between the prior intention and the intended consequences and are likely to be more subtle, more complex, less well understood, and harder to detect than slips. Reason (1990) proposes the following definition of mistakes:

*“Mistakes may be defined as deficiencies or failures in the judgemental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by this decision-scheme run according to plan.”* (Reason, 1990)

## **Violations**

Another more complex category of error is violations. Violations are categorised as any behaviour that deviates from accepted procedures, standards and rules. Violations can be either deliberate or erroneous (Reason 1997). Deliberate violations occur when an actor deliberately deviates from a set rules or procedures. For example, a driver who is deliberately exceeding the speed limit is

committing a deliberate violation. Erroneous or unintentional violations, however, occur when an actor unintentionally deviates from a set of rules or procedures. For example, a driver who is unintentionally exceeding the speed limit (either not comprehending his own vehicles speed and/or not comprehending the current speed limit) is committing an erroneous or unintentional violation. Reason (1997) further distinguishes between three types of deliberate violations: routine, optimizing and necessary violations. Routine violations involve taking short-cuts through procedures in order to achieve a particular task. Optimising violations involve the optimisation of non-functional goals during task performance. Reason (1997) cites the example of a driver (wishing to get from A to B) who optimises speed and indulges in aggressive instincts during the journey from A to B. Necessary violations involve essential deviation from the rules in order to achieve a particular task. For example, when a routine procedure in the workplace is not working, the use of a non-routine procedure to get the job done would be termed a necessary violation.

The slips and lapses, mistakes and violations classification can be demonstrated using Normans seven stages of human action model (Norman, 2001). Norman's seven stages of human action model is a simplistic model of action that divides human action into two processes, execution and evaluation. Execution begins with a goal of some sort, which is then translated into an intention to perform a particular action. This intention is then translated into an action sequence (or set of internal commands) which can be performed to achieve the intention. The final stage of execution is the physical execution of the internal action sequence. The evaluation stage then begins with our perception of the world, which is then interpreted in accordance to our expectations, and then evaluated against our intentions and goals. Norman's seven stages of action model is presented in figure 2.1.

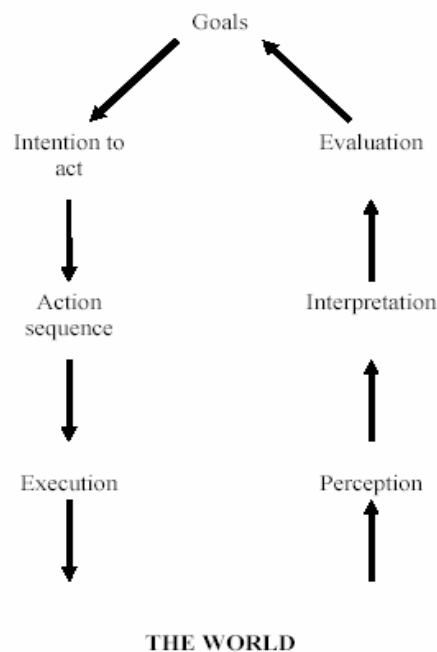


Figure 2.1. Norman's seven stage model of action (Norman, 2001).

Norman’s model can be used to demonstrate where are the origins of the slips and lapses, mistakes and violations described above. Slips are failures in the execution of a particular action, and so their origin lies in execution stage of the human action model. Lapses occur at the storage stage, and so their origin lies between the action sequence and execution stages on Normans model; that is the action sequence is developed, but the execution is not carried out immediately and so the action sequence is stored. Mistakes are errors of intention and so they lie at the intention, interpretation and evaluation stages of Norman’s model. Violations also occur at the intention, interpretation and evaluation stages of the model. A version of Norman’s model of action containing the different error types is presented in figure 2.2.

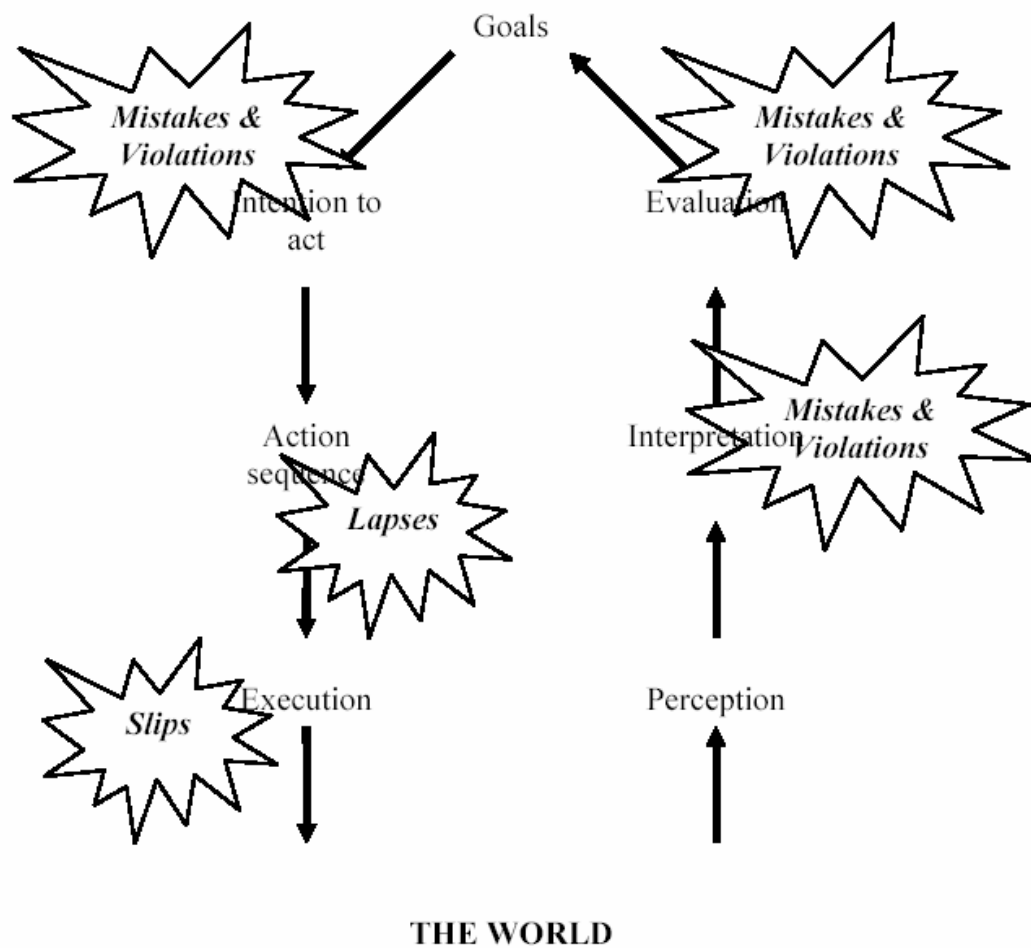


Figure 2.2. Seven stage action model and error types.

The slips and lapses, mistakes, and violations classification described above is the most commonly referred-to classification of different error types. The slips and lapses, mistakes, and violations classification provides a high level scheme for the classification of different error types. However,

for the classification of error types within complex, sociotechnical systems such as the road transport system, it is apparent that further classifications within each of the different error categories are required. In addition to the slips and lapses, mistakes and violations classification, further error types have been specified within each category. For example, Reason (1990) proposed a taxonomy of unsafe acts which prescribes a number of different error types within each of the four error categories. The taxonomy of unsafe acts is presented in figure 2.3.

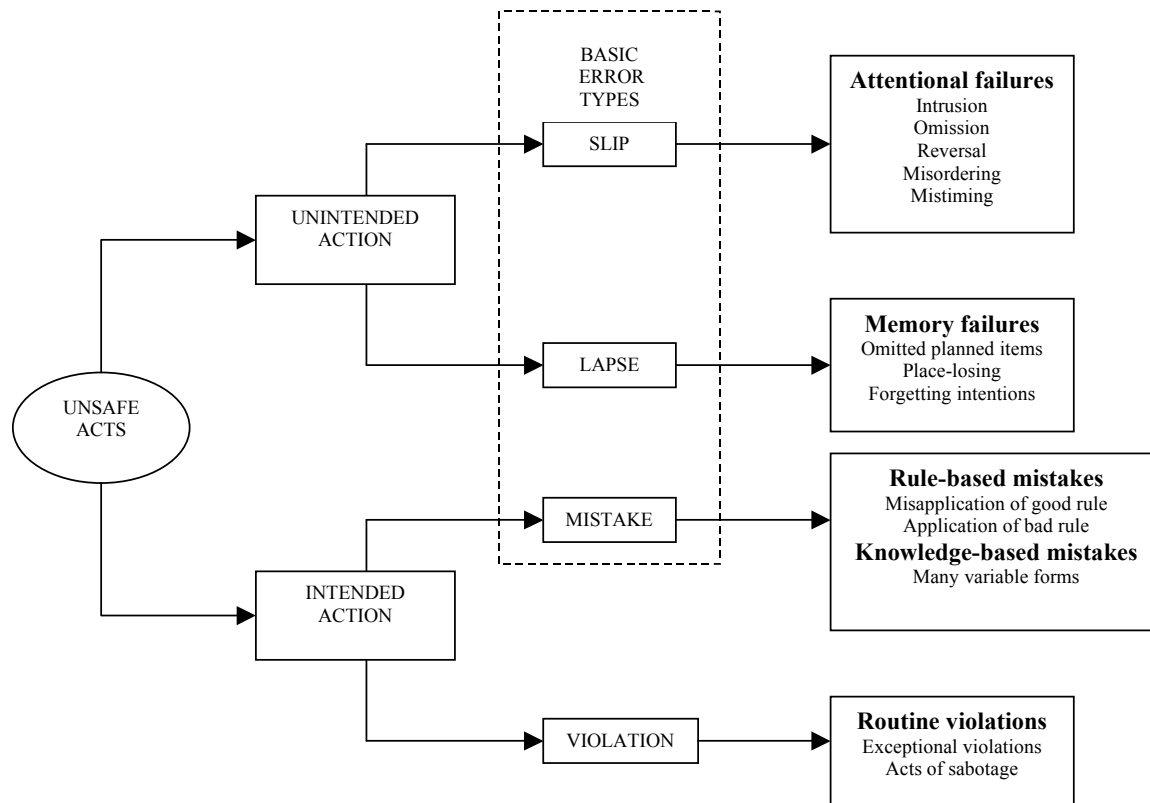


Figure 2.3. Unsafe acts taxonomy (Reason, 1990).

The basic error classification described above offers a simplistic classification of different error types within the slips and lapses, mistakes and violations classification. A number of further, more complex error classifications schemes were identified in the literature. For example, Kirwan (1998a) identifies the following different error types that are of interest in process control risk assessments:

- *slips and lapses*. According to Kirwan (1998a) these error types are most predictable during human error identification (HEI) analyses. Slips are characterised as errors of execution or performance, and lapses are characterised as omissions (e.g. forgetting to perform an action) or sequence errors (task steps performed in the wrong sequence);



- *cognitive errors*: diagnostic and decision making errors. According to Kirwan (1998a) these error types relate to misunderstandings of what is happening in the system. These types of errors include misdiagnosis, partial diagnosis and diagnostic failure;
- *maintenance errors and latent failures*. Maintenance errors occur during maintenance of the system in question (i.e. aircraft maintenance) and result in failure or latent failures that may occur at a later stage during task performance. Latent failures refer to those organisational, operational, design, procedural and training failures that lie dormant within a system;
- *errors of commission*. Refers to those errors that are committed by system operators that are both incorrect and unrequired. Kirwan (1998a) cites the example of locking a valve closed when it should have been locked open as an example of an error of commission;
- *rule violations*. Rule violations are categorized as any behaviour that deviates from accepted procedures, standards and rules. Reason (1990) distinguishes between routine rule violations (whereby the violation is seen as a negligible risk required in order to get a job done) and extreme rule violations (whereby the risk of the violation is understood to be real, and the violation is a serious one);
- *idiosyncratic errors*. These errors refer to those that result from social and emotive influences that might arise during task performance. For example, idiosyncratic errors were commonly seen in the civil aviation domain, where more experienced, authoritarian pilots refused to listen to younger, more inexperienced crew members' opinions on safety-related issues; and
- *software programming errors*. Refers to those errors made by operators when programming software-based control systems (e.g. flight management computer programming in aviation).

Various taxonomies of error have also been proposed in order to aid the classification or identification of different error types in error analysis efforts. Error taxonomies have been used for various purposes, including accident analysis and investigation, human error identification (HEI), human reliability analysis (HRA) and probabilistic safety assessment (PSA). Error taxonomies typically comprise a series of EEMs designed to aid the identification and classification of errors. For example, Swain & Guttman (1983) proposed the following simplistic taxonomy of human error as part of the technique for human error rate prediction (THERP; Swain & Guttman, 1983) HRA approach (Source: Kirwan, 1994):

**1. Error of omission;**

- acts omitted (not carried out).

**2. Error of commission;**

- act carried out inadequately;
- act performed in the wrong sequence;
- act performed too early or too late;
- act performed to either too small or too great an extent;
- act performed in the wrong direction (errors of quality).

**3. Extraneous error;**

- Wrong (unrequired) act performed.

The THERP error taxonomy is used in conjunction with a taxonomy of performance shaping factors to identify credible errors at each step in a particular nuclear power process control procedure. In recent times more sophisticated error taxonomies or classification schemes have been developed for error identification and analysis purposes. For example, Hollnagel (1998) describes the cognitive reliability and error analysis method (CREAM) which uses a complex classification scheme consisting of phenotypes (external error modes), genotypes (causes), antecedents and consequents. The Systematic Human Error Reduction and Prediction approach (SHERPA; Embrey, 1986) was developed for the prediction of human error in the nuclear processing domain. SHERPA uses a taxonomy of errors linked to a behavioural taxonomy. The SHERPA EEM taxonomy is presented in figure 2.4.

**Action Errors**

- A1 - Operation too long/short
- A2 - Operation mistimed
- A3 - Operation in wrong direction
- A4 - Operation too little/much
- A5 - Misalign
- A6 - Right operation on wrong object
- A7 - Wrong operation on right object
- A8 - Operation omitted
- A9 - Operation incomplete
- A10 - Wrong operation on wrong object

**Checking Errors**

- C1 - Check omitted
- C2 - Check incomplete
- C3 - Right check on wrong object
- C4 - Wrong check on right object
- C5 - Check mistimed
- C6 - Wrong check on wrong object

**Retrieval Errors**

- R1 - Information not obtained
- R2 - Wrong information obtained
- R3 - Information retrieval incomplete

**Communication Errors**

- I1 - Information not communicated
- I2 - Wrong information communicated
- I3 - Information communication

**Selection Errors**

- S1 - Selection omitted
- S2 - Wrong selection

Figure 2.4. SHERPA error mode taxonomy.

**Summary**

The literature indicated that there are a number of different error classification schemes and error taxonomies available. The most commonly referred to error classification is the slips and lapses, mistakes and violations classification proposed by Reason (1990). Additionally, a number of domain-specific error classification schemes or taxonomies have also been proposed for use in HEI, HRA and PSA analysis in the nuclear power, process control and aviation domains. Error classification schemes are useful as they can be used to identify and classify the different types of errors made in complex, dynamic systems. They allow safety professionals to identify the different types of errors that are being made in a particular system and also inform the development of appropriate countermeasures. As such, error classification schemes and taxonomies are particularly suited to incident and accident investigation and analysis and also error prediction.

Error classification also enables safety critical issues to be highlighted and error trends to be identified (Shorrock & Kirwin, 2002). However, most classification schemes are limited in that they cannot provide information regarding the psychological and system wide causes associated with the errors made. For this purpose, a number of different theories and models of human error have been proposed. An overview of the human error theory and models presented in the literature is provided in the next section.

## 2.4 Theoretical Perspectives on Human Error

Human error-related research has been conducted since the dawn of psychology. Reason (1990) describes late 19<sup>th</sup> century human error-related studies conducted by prominent psychologists of the era, including Sully, Freud, and Meringer, and also the influence that Gestalt psychologists had upon the study of error. However, the construct remained largely unexplored until the early 1980s when, in response to a number of high profile, high fatality, disasters that were attributed to operator error, such as the Three Mile Island and Bhopal catastrophes, human error-related research increased dramatically. The majority of early research into human error in complex systems focused upon the tendency that operators had for making errors at the so-called ‘sharp-end’ of system operation. Research efforts tended to focus upon error from an individual perspective and human error was seen by many as the major cause of incidents and accidents. Johnson (1999) describes how public attention was focused upon the human contribution to system failure during the 1970s and 1980s due to a number of high profile catastrophes, including the Flixborough, Seveso, Three Mile Island, Bhopal and Chernobyl disasters.

In recent years, however, the focus on human error in complex sociotechnical systems has shifted from the individual operator onto the system as a whole, to consider the complex interaction between latent failures or error producing conditions residing within the system and the errors committed by operators performing activity within the system. Human error is no longer seen as the failure of a particular individual, it is seen as a systems failure. Researchers have now begun to consider how latent failures within systems and errors committed by operators combine to produce incidents and accidents. The systems view on human error and accident causation began to gain recognition in the late 1980s due to a number of high profile accident investigations that highlighted the contribution of latent failures in accident causation. For example, Johnson (1999) points out how investigators focussed upon managerial factors in the wake of the Challenger, Piper Alpha, Hillsborough and Narita catastrophes.

The research conducted to date has culminated in a number of different perspectives on, or approaches to, human error. According to Dekker (2002), there are now two different views on human error, the *old view* and the *new view*. In the old view, human error is treated as the cause of most accidents, the systems in which people work are safe, the main threat to system safety is human unreliability, and safety progress is achieved by protecting systems from human unreliability through automation, training, discipline, selection and proceduralisation. In the new view however, human error is treated as a symptom of problems within the system, safety is not inherent within systems, and human error is linked to the tools used, tasks performed and operating environment. In a similar distinction to the old and new view dichotomy proposed by Dekker, Reason (2000) distinguishes between two different approaches or perspectives: the *person* approach and the *systems* approach. In the following sections, an overview of the two approaches is presented, and selected human error models developed from each perspective are discussed.

## The Person Approach to Human Error

The person approach to human error represents the traditional approach or ‘old view’, and focuses upon the errors that operators make at the so-called ‘sharp-end’ (i.e. the part of the system where human operators perform the activity required for productive activities e.g. control room operation, flightdecks etc) of system operation (Reason, 2000). Person models view error occurrence as the result of psychological factors within an individual. According to the person approach errors arise from aberrant mental processes such as forgetfulness, inattention, poor motivation, carelessness, negligence, and recklessness (Reason, 2000). Person approach-related research typically attempts to identify the nature and frequency of the errors made by operators within complex systems, the ultimate aim being to propose strategies, remedial measures and countermeasures designed to prevent future error occurrence. Whilst person-based research is worthwhile for these reasons, it is often criticised for its contribution to individualistic blame cultures within organisational systems (e.g. operator X made these errors so the incident was operator Xs’ fault) and error countermeasures are ultimately focussed upon reducing the variability in human behaviour.

According to Reason (2000) typical person approach error countermeasures include poster campaigns, additional procedures, disciplinary measures, threat of litigation, retraining and naming, and blaming and shaming. Despite the obvious failings of the person approach to human error (e.g. failure to consider contributory factors in error causation, promotion of blame culture within systems) it still remains the dominant approach in a number of domains. For example, Reason (2000) points out that the person approach is currently the dominant approach in medicine and it is also apparent that the person approach is currently the dominant view held regarding error and accident causation within the road transport domain, whereby post accident blame is typically attributed to individual drivers regardless of the various contributory factors that might have been involved. To summarise, Reason (2000) points out that person approaches to human error are attractive, from some perspectives, for the following reasons:

- attributing blame to individuals is more emotionally satisfying than blaming institutions; and
- removing institutional responsibility is of great interest to managers and is legally more convenient.

However, the person approach to human error is limited in a number of ways, including:

- it promotes a blame culture within systems;
- it treats human error as *the* dominant cause in accidents and incidents;
- it ignores the contribution of latent failures or error causing conditions in systems;
- it prescribes treatments aimed at the individual only, ignoring system-wide issues and problems; and
- it fails to consider error as a consequence of system-wide failure.

Probably the biggest advantages of adopting a person-based approach to error in safety critical systems is the fact that subsequent error countermeasures are aimed entirely at the individual and as a result, system wide failures are to a large extent ignored. In their conclusion to a systems perspective based analysis of the Ladbroke Grove UK rail disaster, Lawton and Ward (2005) point out that attributing the crash only to the individual train driver who missed a stop signal is a

limited view that fails to consider the reasons why the driver failed to stop at the signal and also the interaction between various, complex contributory factors that preceded the incident. Lawton and Ward argue that such a diagnosis would have the further consequence of focussing safety interventions on just one system feature, rather than on the multiple features that combined to cause the accident. This is particularly relevant in the road transport domain, where historically countermeasures have been developed entirely with the driver in mind.

The literature review indicated that a number of different person-based models of human error have been proposed. In the context of this report, person-based models of human error are those that view error from an individualistic perspective, and attempt to classify the types of errors made and also the psychological factors involved. A brief summary of a selection of the person-based models of human error presented in the literature is given below.

### **The Skill, Rule and Knowledge-Based Behaviour Framework**

Reason proposed the Generic error modeling systems (GEMS) which is an error classification scheme that is based upon the SRK model of human behaviour. The SRK framework (Rasmussen, 1983; cited in Vicente, 1999) describes three hierarchical levels of human behaviour: skill, rule and knowledge-based behaviour. Each of the levels within the SRK framework defines a different level of cognitive control or human action (Vicente, 1999). Skill-based behaviour occurs in routine situations that require highly practised and automatic behaviour and where there is only small conscious control on behalf of the operator. According to Vicente (1999) skill-based behaviour consists of smooth, automated, and highly integrated patterns of action that are performed without conscious attention. Reason (1990) points out that error at the skill-based level of behaviour is related to the intrinsic variability of force, space or time co-ordination.

The second level of behaviour, the Rule-based level, occurs when the situation deviates from the normal but can be dealt with by the operator applying rules that are either stored in memory or are readily available; for example emergency procedures. According to Vicente (1999) rule-based behaviour consists of stored rules derived from procedures, experience, instruction, or previous problem solving activities. Errors at the rule-based level of behaviour are typically mistakes associated with the misclassification of situations leading to the application of inappropriate rules or the incorrect recall of procedures (Reason, 1990).

The third and highest level of behaviour is Knowledge-based behaviour, which typically occurs in non-routine situations (i.e. emergency scenarios) where the operator has no known rules to apply and has to use problem solving skills and knowledge of the system characteristics and mechanics in order to achieve task performance. According to Vicente (1999) knowledge-based behaviour consists of deliberate, serial, search based on an explicit representation of the goal and a mental model of the functional properties of the environment. Further, knowledge-based behaviour is slow, serial and effortful as it requires conscious, focused attention (Vicente, 1999). Errors at the knowledge-based level of behaviour are typically mistakes arising from resource limitations and incomplete or incorrect knowledge (Reason, 1990). The SRK framework is presented in figure 2.5.

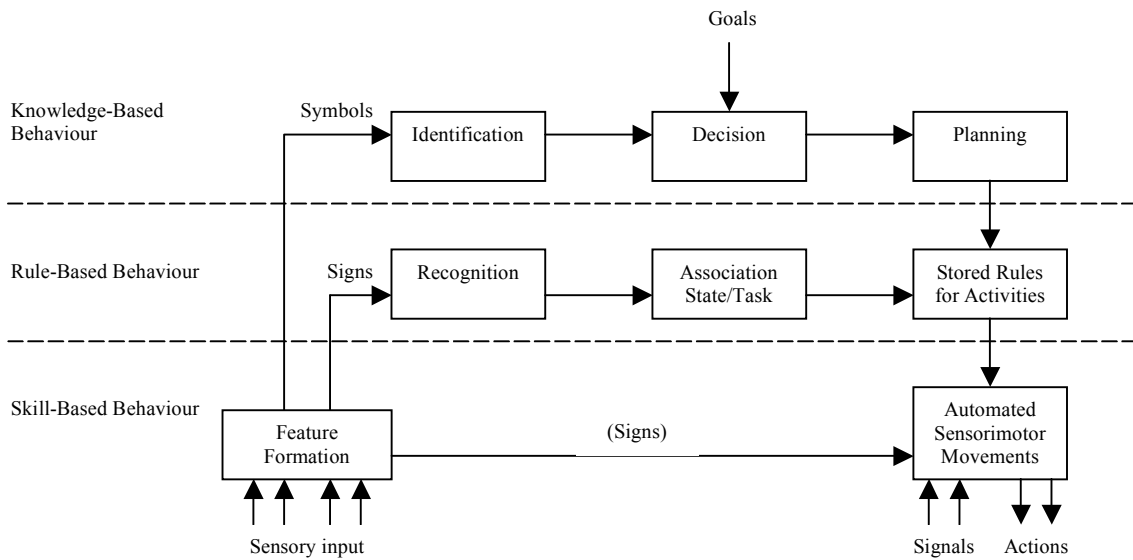


Figure 2.5. The SRK model of human performance (adapted from Vicente, 1999).

### The Generic Error Modelling System

Reason (1990) presents a conceptual framework for identifying the origins of the different error types from the slips, lapses, mistakes and violations classification scheme described previously in this chapter. The generic error modeling system (GEMS) is an error classification scheme that is based upon Rasmussen’s SRK framework. GEMS attempts to describe the error mechanisms at each of the three levels of behaviour proposed by the SRK framework. According to GEMS, there are three basic error types: skill-based slips and lapses, rule-based mistakes and knowledge-based mistakes. Slips and lapses occur at the skill-based level of human behaviour (i.e. prior to the identification of a problem) and are mainly categorised as monitoring failures. Those errors that arise once a problem is identified (at the rule and knowledge behaviour levels) are rule and knowledge based mistakes, and are categorised as problem solving failures. The distinction between error types and performance levels proposed by GEMS is presented in table 2.1.

Table 2.1. SRK error distinction (adapted from Reason, 1990).

Performance level	GEMS Error type	Failure type
Skill-based level	Slips and lapses	Monitoring failures
Rule-based level	Rule-based mistakes	Problem-solving failures
Knowledge-based level	Knowledge-based mistakes	

The GEMS framework is presented in Figure 2.6. According to the framework, routine performance occurs at the skill-based level of behaviour. This comprises segments of pre-programmed behavioural sequences combined with attentional progress checks designed to establish whether actions are running according to plan and also whether the current plan is adequate to achieve the desired outcome. Errors at the skill-based level of behaviour typically comprise slips and lapses caused by inattention and over-attention. Reason (1990) labels these errors as *control mode failures*. The GEMS framework proposes that when confronted with a problem, operators initially search for a solution at the rule-based level. If a solution at the rule-based level cannot be found, then the operator moves to the more taxing knowledge-based level for a solution. Thus, the GEMS framework proposes that rule-based problem solving will always be attempted first. If successful (the rule-based cycle may be repeated several times until a solution is derived) the operator then returns to the skill-based level of behaviour. The operator only switches to the knowledge-based level upon the realisation that none of the rule-based solutions is appropriate or adequate for the problem in question. Once a solution is identified at the knowledge-based level, a new set of skill-based routines is required. According to Reason, this involves borrowing routines from other activities via rapid switching between the skill-based and rule-based levels. This continues until ‘normal’ performance is resumed. Errors at the rule and knowledge-based levels of behaviour are therefore categorised as problem-solving failures involving either rule-based mistakes or knowledge-based mistakes. A brief description of each mistake type is presented below:

- *rule-based mistakes*. Rule-based mistakes typically involve the misapplication of good rules, the application of bad rules or the failure to apply a good rule;
- *knowledge-based mistakes*. Knowledge-based mistakes occur when humans have to think of problem solutions on-line during task performance (Reason 1997); that is, during non-routine situations.

Within the GEMS framework, several error types are proposed for each of the three behaviour levels. A breakdown of the error types is presented in Table 2.2.

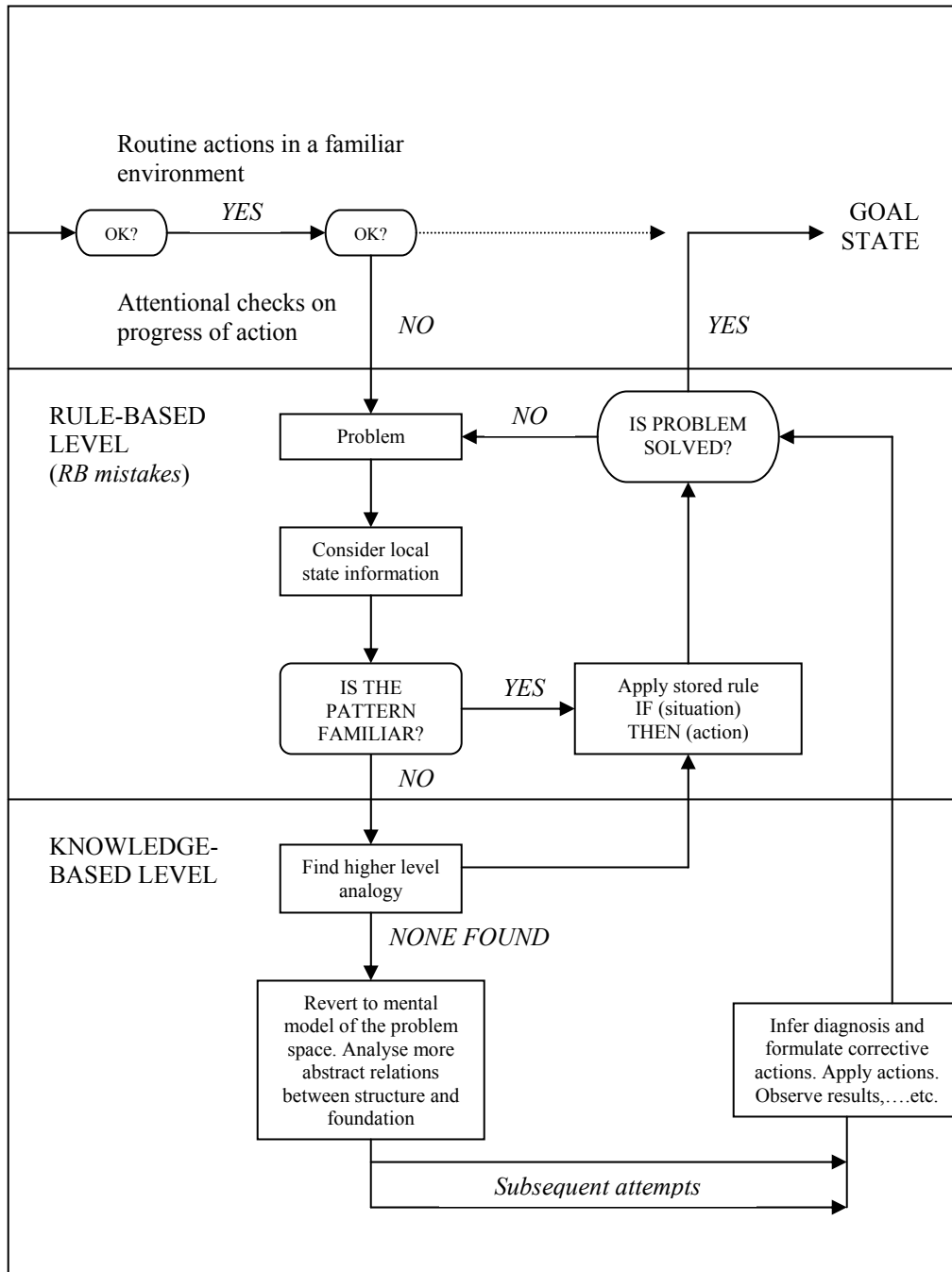


Figure 2.6. GEMS framework (Source: Reason, 1990).



Table 2.2. GEMS failure modes (Source: Reason, 1990).

<b>Skill-based performance</b>	
<i>Inattention</i> Double-capture slips Omissions following interruptions Reduced Intentionality Perceptual confusions Interference errors	<i>Overattention</i> Omissions Repetitions Reversals
<b>Rule-based performance</b>	
<i>Misapplication of good rules</i> First exceptions Countersigns and nonsigns Informational overload Rule strength General rules Redundancy Rigidity	<i>Application of bad rules</i> Encoding deficiencies Action deficiencies Wrong rules Inelegant rules Inadvisable rules
<b>Knowledge-based performance</b>	
Selectivity Workspace limitations Out of sight out of mind Confirmation bias Overconfidence Biased reviewing Illusory correlation Halo effects Problems with causality Problems with complexity Problems with delayed feedback Insufficient consideration of processes in time Difficulties with exponential development Thinking in causal series not causal nets Thematic vagabonding Encysting	

In summary, the GEMS framework is a person-based human error classification scheme that describes the types and origins of errors and mistakes at each of the three levels of behaviour proposed in the SRK framework. Errors at the skill-based level of behaviour are mainly caused by monitoring failures involving inattention and over-attention. Mistakes at the rule-based and knowledge-based level of behaviour are associated with problem solving. Rule-based mistakes are divided into two categories: the misapplication of good rules and the application of bad rules. Knowledge-based mistakes are caused by bounded rationality and incomplete knowledge regarding the problem situation.

### **Rasmussen's Model of Human Malfunction**

Rasmussen (1982) presents a model of error or 'human malfunction' that considers five key aspects associated with error occurrence. The model describes what went wrong (the internal mental function that failed), how it went wrong (the internal failure mechanism), why it went wrong (the causes), the external task being performed, and the effects of the error upon the external task (the external mode of malfunction). According to Rasmussen these factors combine

to produce a description of human error in the form of a causal chain of events (Rasmussen, 1982). The causal chain of events error model is presented in Figure 2.7.

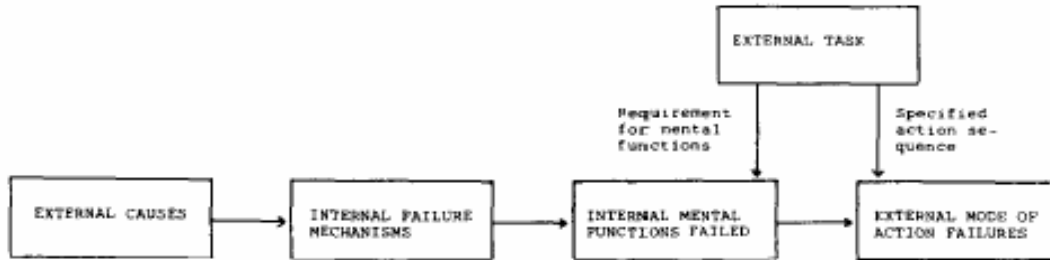


Figure 2.7. Human error causal chain of events (Rasmussen, 1982).

Rasmussen (1982) also proposed a human malfunction classification system which considers the contributory factors (e.g. performance shaping factors, situational factors, task related factors etc) associated with human malfunction or error. The model is presented in Figure 2.8.

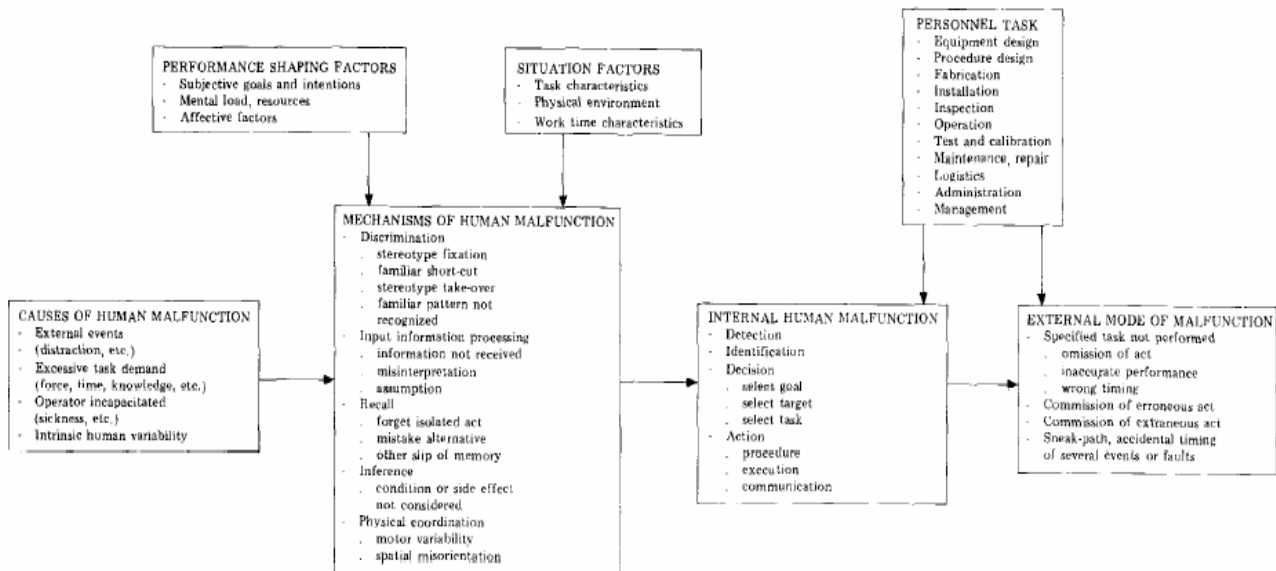


Figure 2.8. Rasmussen's taxonomy of human malfunction (Source: Rasmussen, 1982).

Rasmussen proposed that the taxonomy of human malfunction be used for the collection and classification of human error data. The taxonomy is particularly useful as it considers both the internal (e.g. mechanisms of human malfunction) and external causes (e.g. performance shaping factors, situational factors and personnel task) of a particular human error, and also the internal malfunction (e.g. detection, identification) and external form (e.g. omission of act, commission of erroneous act) that a particular error may take. In addition to the human malfunction taxonomy, Rasmussen (1982) presents a series of flowcharts designed to aid the analysis and classification of errors. These include a guide for identifying the internal human malfunction, a guide for identifying the mechanism of human malfunction (e.g. how it failed), and a guide for identifying the external causes of human malfunction (why it failed). The guide for identifying the external causes of human malfunction is presented in Figure 2.9.

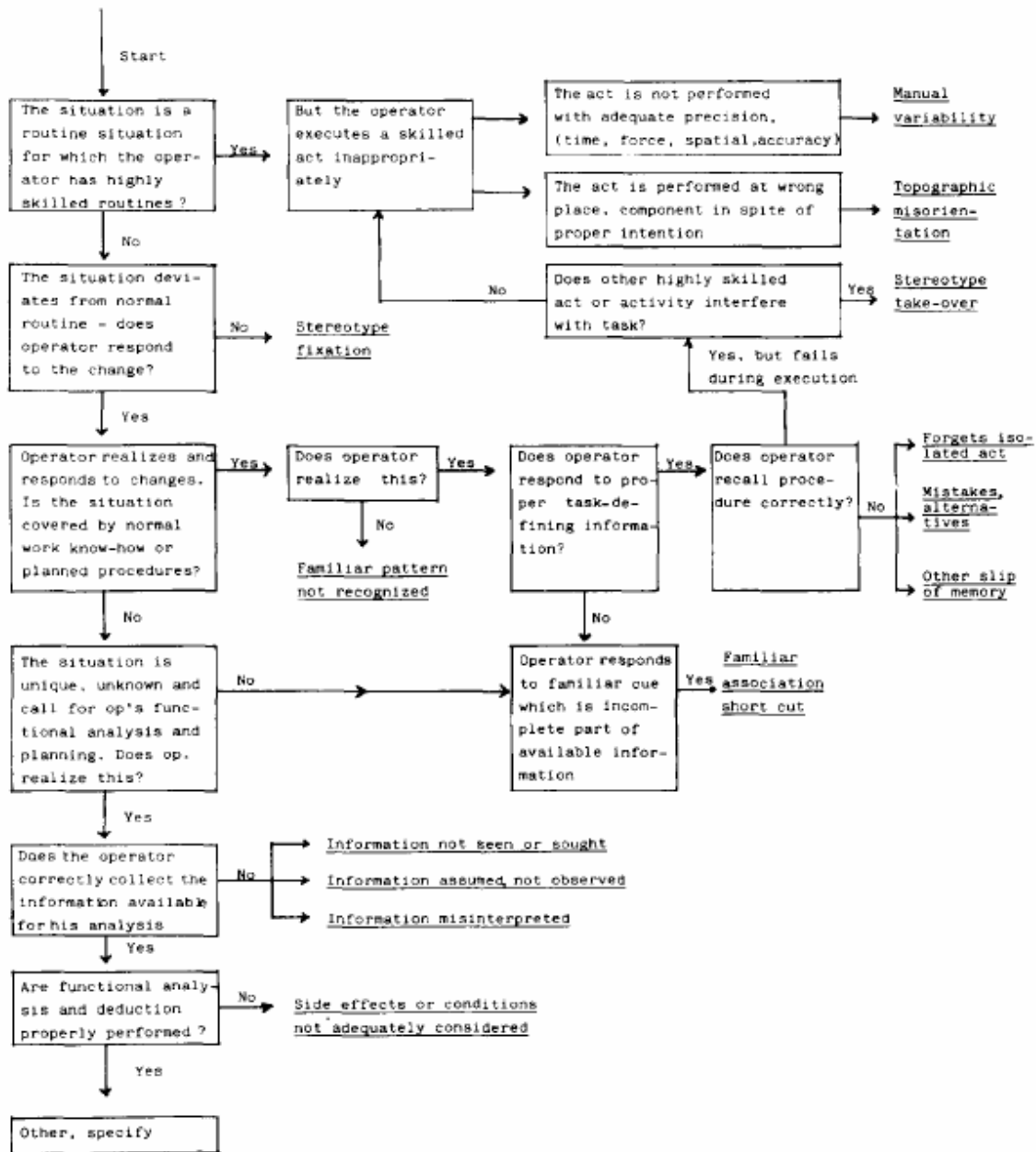


Figure 2.9. Guide for identifying the mechanism of human malfunction (Source: Rasmussen, 1982).

### The Systems Perspective Approach to Human Error

The other approach to human error in complex systems is the systems perspective approach. The systems approach treats error as a systems failure, rather than an individual operator's failure. Rather than focusing entirely upon individual errors made at the so-called sharp end of system operation, systems approaches take a system-wide perspective on error, and consider the presence

of latent or error-causing conditions within systems and their role in the errors made at the sharp-end by operators. Systems approaches purport that the errors made by operators at the sharp-end are a consequence of the error-causing or latent conditions residing with the system. Unlike the person approach, human error is no longer seen as the primary cause of accidents, rather it is treated as a consequence of the latent conditions within the system. It is a combination of error-causing conditions and operator errors that result in incidents and accidents. The notion that human error is a consequence of latent failures rather than a cause of catastrophes was first entertained by Chapanis in the 1940s (1949; cited in Stanton & Baber, 2002), who, in conclusion to an analysis of landing gear related incidents, suggested that ‘pilot error’ was really ‘designer error’. The systems approach has received increased attention in recent years, and is currently being adopted as an approach to error and error management in a number of complex, sociotechnical systems, such as the aviation and nuclear process control domains. There are a number of advantages associated with the systems approach to error, namely:

- it considers the latent conditions throughout the system that contribute to the errors made by operators at the sharp end;
- it removes the apportioning of blame to individual operators within the system;
- it recognises the fallible nature of humans and accepts that errors will occur;
- it promotes the development of appropriate countermeasures that are designed to treat both the latent conditions within the system and the errors made by operators; and
- it promotes the development of error tolerance within systems.

The systems approach to human error assumes that humans are fallible and errors are the inevitable consequence of inadequate conditions residing within complex systems. The systems perspective model of human error and accident causation in complex systems proposed by Reason (1990) is probably the most influential and widely recognised systems approach to error, and indeed of all human error models presented in the literature. The systems perspective or ‘Swiss cheese’ model as it is better known (due to its resemblance to a series of slices of Swiss cheese) considers the interaction between latent failures and errors and their contribution to organisational accidents.

According to the model, complex systems consist of various different organisational levels that contribute to production (e.g. decision makers, line management, productive activities and defences). At each of the different layers within the system, there are various defence layers designed to prevent occupational accidents. Defences might include protective equipment, rules and regulations, training, checklists and engineered safety features. Holes or weaknesses in these defences, created by the latent conditions and active errors create ‘windows of opportunity’ for accident trajectories to breach the defences and cause an accident. Such ‘windows of opportunity’ are rare due to the multiplicity of the systems defences and the mobility of the holes (Reason, 1997).

According to the systems perspective, organisational accidents occur when the holes in the systems defences line up in a way that allows the accident trajectory to breach each of the different defence layers. Latent conditions and active errors combine in such a way that the accident is ‘allowed’ to happen. On most occasions, accident trajectories are halted by defences at the different levels in the system. However, on rare occasions, the holes or windows of opportunity line up to allow the accident trajectory to breach all of the systems defences,

culminating in an accident or catastrophe. The same accident trajectory on another occasion may not have breached all of the defences, were the windows of opportunity not present due to adequate defences being in-place. An adaptation of the systems perspective model is presented in Figure 2.10. In Figure 2.10, the accident trajectory is allowed to breach the defences at each of the different levels due to the holes or 'windows of opportunity' created by latent failures and active errors. A brief description of active errors, latent failures and each of the failure levels in the systems perspective model is given below.

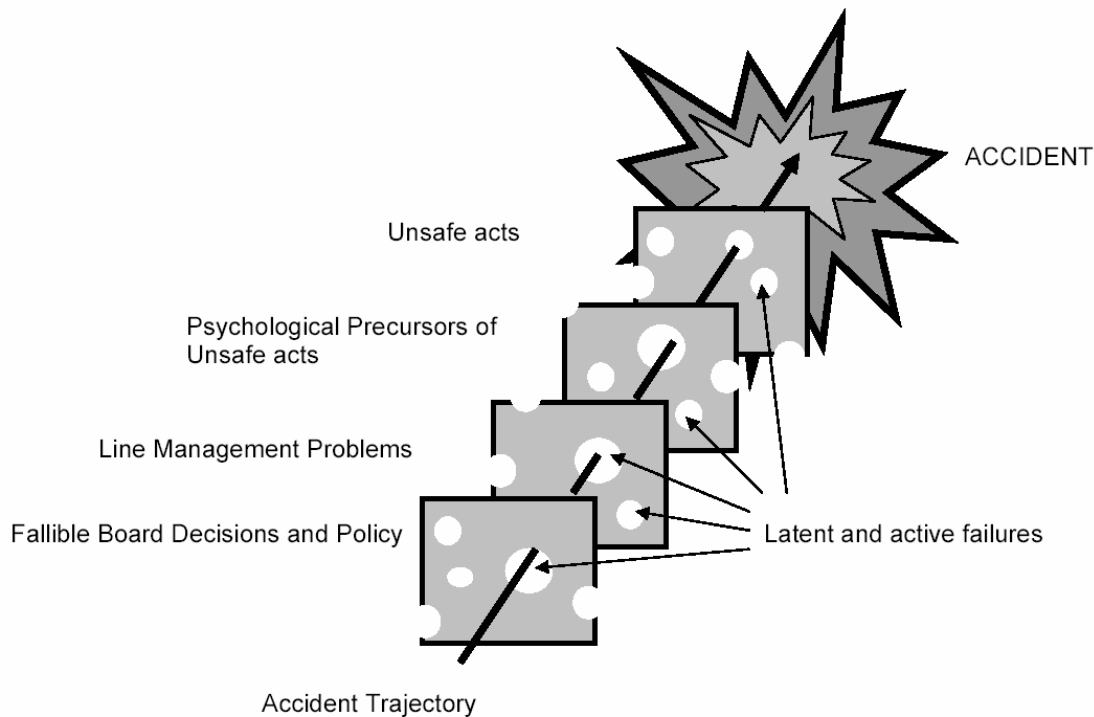


Figure 2.10. Systems perspective model of accident causation in complex systems (adapted from Reason, 1990).

## Latent Conditions and Active Errors

Reasons system perspective model considers the complex interaction between latent failures or conditions and active errors within complex systems. Latent failures are those inadequate conditions or failures residing throughout a system that may contribute to the breach of system defences. Examples of latent conditions within complex systems include poor designs, inadequate supervision, manufacturing defects, maintenance failures, inadequate training, clumsy automation, inappropriate or ill-defined procedures, inadequate equipment and procedural short cuts, to name only a few. Latent conditions are present in all systems, and are typically the result of top-level decisions made by governments, regulators, manufacturers, designers and organizational managers (Reason, 1997). Latent conditions can be present within a system for a significant period of time without any adverse effect before they are either recognised and removed or combine with local conditions and active errors to cause an accident.

Active errors (also known as unsafe acts), on the other hand, represent those errors that are committed by human operators at the so-called 'sharp-end' of system operation that have an immediate impact upon system safety. In the aviation domain, for example, errors and violations committed by the flight crew would be classified as active errors. Reason (1997) identifies two important distinctions between active errors and latent failures. Firstly, active errors typically have immediate and short-lived consequences, whilst latent conditions can lie dormant for long periods of time without causing any harm. Secondly, active errors are committed by front line operators at the sharp end of the system, whilst latent conditions are typically created by the upper levels of organisational, regulatory and government hierarchies.

The Mont St Odile civil aviation disaster provides a simple demonstration of the interaction between active errors and latent conditions in accident causation. The disaster involved an A320-111 passenger aircraft impacting the side of a mountain in Strasbourg in 1992, which claimed the lives of 87 people. The crash was attributed to pilot error caused by a faulty cockpit design which led the flight crew to inadvertently select a 3,300 feet per minute descent rate instead of the required 3.3° flight path on the aircraft's approach to Strasbourg airport. In this case, the selection of a 3,300 feet per minute rate of descent represents the active error, whereas the faulty design (dual control functionality) of the vertical speed/flight path angle control and display represents one of the latent conditions that led to the error.

### **Fallible Board Decisions and Policy**

The first level of failure defined by Reason's systems perspective model is the fallible board decisions and policy level. The systems perspective model assumes that accidents in complex systems originate primarily from fallible decisions made by system designers and higher level management. Reason (1990) stresses that this is not an allocation of blame, but recognition that in organisations a significant portion of influential decisions will ultimately be fallible. Fallible board decisions and policy represent board decisions and policy that create latent conditions within the system. Examples of fallible board decisions and policy include the selection of inadequately designed equipment, the vetoing of system improvement measures and the use of policies that incur time pressure on agents within the system.

### **Line Management Problems**

The next level of failure in the systems perspective model is the line management level. According to Reason (1990), line management problems arise from incompetent management and also the fallible board decisions and policy from the preceding level in the model. Line management problems represent those instances where management is either inadequate and/or inappropriate. Examples of line management problems include inadequate management or supervision and the use of inadequate or inappropriate training and procedures.

### **Psychological Precursors of Unsafe Acts**

The psychological precursors of unsafe acts failure level represent latent states that create the potential for unsafe acts. According to Reason (1990), the precise nature of unsafe acts is defined through the complex combination of a number of factors, including the task being performed, the environmental conditions and the presence of hazards. Each precursor can contribute to a great

number of unsafe acts, depending upon the associated conditions. Examples of these precursors include poor motivation, negative attitudes, and a failure to perceive hazards. The majority of the precursors apparent at this level are directly related to the human operators performing activity within the system. However, these precursors are either exaggerated or mitigated by the decisions made at the board and subsequent management levels within the system.

## Unsafe Acts

The unsafe acts level of failure in the systems perspective model represents the errors committed by operators at the so-called 'sharp-end' of system operation in the presence of potential hazard(s). According to Reason (1990), the commission of these unsafe acts is determined by a complex interaction between intrinsic system influences existing at the preceding levels in the system perspective model and influences from the outside world, such as environmental factors. Reason stipulates that unsafe acts are more than simply errors and violations committed by agents within the system; they are errors and violations committed in potentially hazardous situations. For example, the error in the Strasbourg disaster cited above was the selection of a 3,300 feet per minute rate of descent instead of the required 3.3° flight path angle. This error only became an unsafe act when the aircraft was in close proximity to the mountain that it impacted. The same error committed away from mountainous terrain would not have constituted an unsafe act.

## Inadequate Defences

According to the systems perspective model, a system has various defences at each of its organisational levels that are designed to stop accidents occurring. System defences take many different forms, ranging from personal safety equipment such as safety helmets, to more sophisticated system-wide defences such as the automatic safety devices and levels of containment used in nuclear power plants (Reason, 1990). Reason (2005) broadly defines two types of defence: *hard* defences and *soft* defences. Hard defences are engineered safety features, whilst soft defences are 'people and paper' defences, such as laws, rules, procedures, checking, sign-offs and auditing. According to Reason (2005), system defences serve the following common protective functions:

- they keep people informed about the nature of the dangers;
- they offer guidance on how to do the job without harm;
- they highlight or provide warnings of dangers and threats;
- they protect assets and possible victims;
- they return systems to a safe state; and
- they prevent hazardous materials from coming into contact with possible victims.

Defences in complex systems can only be breached by a combination of several different causal factors, including latent conditions and local triggering events such as the occurrence of unsafe acts within specific circumstances that are usually associated with some atypical system condition. For example, Reason (1990) cites the unusually low temperature that preceded the launch of the Challenger shuttle, and the previously unseen testing conducted prior to the annual shut-down at Chernobyl.



The systems perspective on human error is perhaps best explained through the retrospective analysis of a large-scale accident or catastrophe. For this purpose, we will use the Herald of Free Enterprise disaster at Zeebrugge. The Herald of Free Enterprise ferry capsized in shallow waters just outside Zeebrugge harbour on the 6th March 1987, killing 150 passengers and 38 crew. The immediate cause of the disaster, the flooding of the lower deck, was attributed to the ferry setting sail with her inner bow doors open. This assumes that the assistant bosun was to blame for not closing the bow doors, and also that the ship's captain was to blame for setting sail with the bow doors open. A systems perspective creates a more complex account, highlighting a number of different contributory factors that led to the catastrophe.

Using Reasons (1990) systems perspective, the causal active errors are the assistant bosun's failure to close the ships bow doors and the captain's decision to set sail. However, moving 'upstream' from the accident itself, the investigation revealed a number of other latent conditions that combined to allow the accident to happen. There were a number of preconditions for unsafe acts and line management failures, including the assistant bosun's level of fatigue, poor rostering (the assistant bosun was in fact asleep in his cabin, having recently been relieved from other additional duties), the bosun's failure to shut the bow doors even though he actually recognised that they were open (he felt that it was not his job to shut them), the bosun's apparent sighting of the assistant bosun heading towards the bow doors, pressure on the crew to depart early due to delays at Dover and the 'choppy' sea conditions on the day of the disaster. There were also a number of board and policy failures, including a negative reporting culture within the company which ensured that the master did not know of any problems encountered previously, the failure to install a bow door indicator on the bridge despite repeated requests, and the unsafe top heavy design of the ferry involved. Taking a systems perspective, therefore, allows the investigator to identify the various latent conditions that led to the causal errors involved in the catastrophe. According to Reason (1990), the subsequent accident investigation into the Herald of Free Enterprise disaster was unique in that, as well as identifying the causal errors, management's role in the disaster was also highlighted.

Lawton and Ward (2005) used a similar framework to analyse the Ladbroke Grove Rail disaster in which 31 people were killed and over 400 injured. The incident involved a collision between a turbo train and a high speed train close to Paddington station in London, UK. The immediate cause was identified as a failure of the turbo train to stop at a red signal. Lawton and Ward (2005) investigated the incident using a systems perspective to identify the factors that contributed to the signal violation. Their analysis revealed that a number of factors contributed to the accident, including active errors (turbo driver failing to stop at stop signal SN109, signaller failing to take appropriate action), local working conditions (inexperience, expectation, attention capture, strong motor programs, false perceptions, confirmation bias and incomplete knowledge), situational and task factors (track layout complexity, poor human system interface, poor system feedback and poor communications), inadequate defences (omission/weakness of safety devices, poor signalling, inadequate polices, standards and controls, and limited driver awareness of hazards), organisational failures (poor safety management, poor training, poor planning and the Paddington station layout).

The systems perspective model of human error was unique in that it considered not only the errors committed by operators within complex systems, but also the latent conditions and failures caused by the different organisational levels within complex systems that contribute to error occurrence. Reason's model redefined the construct of human error and subsequent research

began to consider system wide contributions to human error and accidents. Error began to be treated as a *consequence* of latent failures within systems, rather than the primary *cause* of accidents and incidents. The systems perspective model is a simplistic, intuitive approach to human error and provides a useful insight into the interaction of latent failures and errors within complex sociotechnical systems and their role in accident causation in complex systems. The model is particularly useful for the retrospective analysis of accidents and incidents because it removes the focus from the individual operator error onto the latent failures existing in the system as a whole. In addition to analysing human error at the sharp end, the model encourages practitioners to consider the latent conditions within the system that combine to cause the errors involved in the accident. This leads to a comprehensive breakdown of the causal factors involved in the accident under analysis. Additionally, the model's simplicity allows it to be applied by practitioners with little or no experience of psychology and human factors theory or methods. Further, the model is generic and can be applied to any domain, and countermeasures derived from systems perspective based analyses are aimed at the entire system, and not just individual operators.

Despite the model's appeal it does have a number of distinct flaws. Firstly, the model lacks a clear definition of the different latent failures residing at each of the levels within the model. Consequently, analysts are given little guidance in the identification of these latent failures. Secondly, the model lacks a taxonomy of active errors or 'unsafe acts'. Consequently, analysts are given little guidance in the identification of the errors and violations involved in accident or incident scenarios. The lack of specification of the different latent failures and unsafe acts may, in part, be attributed to the generic nature of the model; to specify the latent failures and unsafe acts would limit the model to a particular domain. The latent failures residing within a rail transport system might not be, for example, the same as the latent failures residing within an oil production system. Thirdly, the model is descriptive rather than analytical. Finally, Wiegmann & Shappell (2003) point out that because the model was originally aimed at academics rather than practitioners, the explanation of the unsafe acts level was highly theoretical and analysts and investigators have had difficulties applying the model in the 'real-world' of aviation.

The systems perspective model proposed by Reason remains the dominant model of human error within the literature, although other systems perspective models of error have been proposed. For example, the SHELL model proposed by Edwards (1988; cited in Wiegmann & Shappell, 2003) describes four basic components necessary for successful man-machine interaction and design (Wiegmann & Shappell, 2003). These are software, hardware, environment and liveware. Software refers to the rules and regulations that govern how a system operates. Hardware refers to the hardware used within a particular system, including equipment and materials. The environment refers to the environmental conditions in which operators in a particular system work. Liveware refers to the human operators who perform activity within a system. According to the SHELL model, the four components described above interact with one another during system operation and failures occur where there is a mismatch between the software, hardware, environment or liveware components. For example, there could be a mismatch between the hardware (equipment) and the liveware (human operator) within a particular system which leads to an error being made. The SHELL model is popular and in 1993 the International Civil Aviation Authority recommended that it be used as a framework for analysing human factors during aviation accident investigation (Wiegmann & Shappell, 2003).

Moray (1994; cited in Strauch, 2005) presents a systems perspective model of error in complex systems which proposes that error results from the elements that comprise a particular system. These elements include the equipment, the operator (individual and team), the company and management, the regulator and societal and cultural factors. According to Moray's model, each system component affects system operation and creates opportunities for error (Strauch, 2005). For example, poor equipment, inadequately trained operators, and poor management can all lead to errors made by human operators.

## 2.5 Summary

In the preceding sections the construct of human error has been described with regard to its definition, the different types of errors identified previously, and the different models and theoretical perspectives of human error that currently dominate the literature. The authors acknowledge that this overview of human error-related research and associated theory is not exhaustive, and that additional models and theories of human error exist. To present a completely exhaustive description of the human error literature is, however, beyond the scope of this project. Rather, models have been selected on the basis of their prominence within the human error literature and their relevance to this program of research.

The literature indicates that there have been numerous attempts at defining the construct of human error, and also that various error classification schemes, models and taxonomies have been proposed for use in a number of different domains. The literature also indicates that there are currently two dominant approaches to the understanding of human error: the person approach and the systems approach. It was concluded that the human error-related research conducted to date in complex, dynamic domains can be broadly classified as either person approach-related research or systems approach-related research.

We further concluded that the majority of initial human error-related research can be broadly categorised as person-based. Person-based human error research focuses upon the identification and classification of the errors made by individual actors, and seeks to identify the internal or psychological factors (e.g. inattention, invigilance and carelessness) involved in error occurrence. As a result of this research, error classification schemes (e.g. slips and lapses, mistakes and violations), taxonomies (e.g. SHERPA) and models of human error (e.g. GEMS) have been developed which attempt to describe and classify the myriad of different error types and the underlying psychological causes involved. More recently, however, human error-related research has adopted a different point of view regarding error and accident causation in complex, sociotechnical systems. Systems approaches consider the combined role of latent conditions and errors in accident causation. Human error is no longer treated as the primary cause of incidents and accidents; rather it is seen to be a consequence of the latent conditions residing throughout systems.

Systems-based approaches are currently receiving increased attention from safety managers in complex, sociotechnical systems, and are attractive for a number of reasons including their consideration of the different contributory factors involved in accidents, the removal of an individualistic blame culture and the development of system-wide countermeasures that they facilitate. It was also concluded, however, that, despite the recent increase in systems based research the dominant view on human error in a number of safety-critical domains (including the

road transport domain) is still the person-based view, and that this is detrimental to safety and error management because countermeasures are aimed at the individual, ignoring the latent conditions that reside within a particular system. In the next chapter, the concept of human error management in complex systems is introduced and an overview of error management programs and the different error management-related approaches, techniques and methodologies available is presented.

## Chapter 3 Human Error Management

### 3.1 Introduction

In the preceding chapter, an overview of what is known about human error in complex, sociotechnical systems was presented. The literature indicates that there is a large body of information on the different types of errors that are committed in such systems, the frequency with which they are made, and the consequences of the different types of errors. This information is typically used to develop countermeasures designed to reduce future error occurrence. Despite this, the literature also indicates that actors, regardless of skill, experience and training, continue to make errors during task performance and that these errors continue to impact system safety in complex, sociotechnical systems. Consequently further measures are required to reduce, mitigate and manage human error in such domains. So called error management programs are employed for this purpose in safety-critical systems and use formal methods to develop a deeper understanding of the nature of, and factors surrounding, error occurrence in a particular system. The ultimate goals of such programs is, through a variety of means, the eradication, reduction, management or mitigation of errors and their consequences within the system in question. Helmreich (2000) offers the following definition of error management.

*“Error management is based on understanding the nature and extent of error, changing the conditions that induce error, determining the behaviours that prevent and mitigate error, and training personnel in their use.” (Helmreich, 2000).*

According to Reason (2005) error management has two components: *error prevention* and *error containment*. Error prevention involves the use of strategies designed to identify and prevent the incidence of errors. Error prevention strategies include the identification and removal of error traps, user-friendly equipment, training, briefings and de-briefings. Error containment involves the use of strategies designed to limit the consequences of those errors that do occur. Error containment acknowledges that errors will continue to occur and containment strategies include error detection and recovery training and the design of error-tolerant systems. According to Reason (1997) error management includes measures to:

- minimise the error liability of individuals and teams;
- reduce the error vulnerability of tasks and/or task elements;
- determine, assess and eliminate error-producing factors within the workplace;
- identify organizational factors that create error producing factors within the individual, team, task and workplace;
- enhance error detection;
- increase the error tolerance of the system;
- make latent conditions visible to those concerned with system operation and management; and

- improve the organisations intrinsic resistance to human fallibility.

Reason emphasises that a basic principle of error management is that the best people can sometimes make the worst errors. He describes the following basic elements of human nature and error (Reason, 1997):

- human actions are almost always constrained by factors beyond an individual's immediate control;
- people cannot easily avoid actions that they did not intend to perform in the first place;
- errors have multiple causes: personal, task-related, situational and organisational factors; and
- within a skilled, experienced and largely well intentioned workforce, situations are more amenable to improvement than people are.

In a recent error management workshop aimed at organizational safety managers, Reason (2005) proposed the following five fundamental policies of error management:

- zero tolerance for reckless behaviour;
- blame-free incident reporting;
- safety information systems designed to identify recurrent error traps;
- training in the skills (mental) necessary for error detection and recovery; and
- collective mindfulness of danger.

Reason (1990) points out that comprehensive error management should be directed at the different levels of an organisation including the team, the task, the workplace, and the organisational processes.

Despite the widespread implementation of error management programs in different domains, Reason (1997) suggests that the implementation of a principled and comprehensive error management program is very rare and most error management efforts are typically piecemeal, reactive, and event-driven (rather than planned, pro-active, and principle driven as they should be). Additionally, Reason purports that typical error management programs ignore the developments in behavioural sciences that have occurred over the past three decades in the understanding of the nature, variety, and causes of human error. Consequently, Reason highlights the following problems associated with existing error management strategies:

- they focus upon the retrospective 'firefighting' of errors that have already occurred rather than the anticipation and prevention of errors;
- they focus upon active errors rather than the latent conditions residing in the system;
- they focus upon the individual rather than organizational, contextual and environmental factors;
- they rely heavily on exhortations and disciplinary sanctions;
- they use blame-laden terms such as 'carelessness' and 'irresponsibility';
- they do not distinguish between random and systematic error-causing factors; and
- they are not informed by current human factors knowledge regarding error and accident causation.

Error management programs use a variety of methods in managing error. Consequently, a great number of error management methods exist. As a result of the literature review, a number of different error management-related approaches were identified. An overview of the different approaches to error management in complex, dynamic systems is presented in the following section.

## **3.2 Error Management-Related Techniques**

Error management programs employ a variety of different approaches, methodologies and techniques to address the problem of error. The literature review indicated that there is a plethora of techniques that are related to error management in complex, dynamic systems. For example, Reason (1997) cites a wide selection of error management related techniques, including selection, training, licensing and certification, skill checks, human resource management, quality monitoring and auditing, technical safety audits, unsafe act auditing, hazard management systems, procedures, checklists, rules and regulations, administrative controls, total quality management, probabilistic safety assessment, human reliability analysis, human error identification, and crew resource management. A key feature of an effective error management program is the collection of specific information on the different types of human error made:

- the nature of the errors committed;
- the factors contributing to and causing them;
- the tasks and equipment involved;
- their consequences; and
- how they were recovered from.

Such information is then used, amongst other things, to inform the design and development of error tolerant systems, and the development of countermeasures, remedial measures and strategies designed to eradicate or reduce error in systems. There are a number of different ways to collect and classify human error data. These include the use of incident reporting systems, accident investigation and analysis procedures, traditional data collection techniques (observational study, interviews, questionnaires etc), human error identification (HEI), human reliability analysis techniques (HRA) and error modelling. Due to the importance of collecting human error data, those techniques used for such purposes are included here in the review of error management techniques.

The types of error management approaches employed within a particular system depends on the domain, system and organisation involved. Different regulatory bodies and organisations all have their own different approaches to error management. Normally a mixture of approaches is used but, as Reason (2005) points out, there is no single best approach to error management and the mixture of practices, techniques and measures should be determined on the basis of the culture in question. Error management techniques are required for each of the different components within a particular system including the person, the team, the task, the workplace, the organisation and the system itself (Reason, 2005).

The literature review identified well over one hundred error management and data collection-related techniques and it is beyond the scope of this report to provide an exhaustive review of all of them. Rather, a review of selected error management and error data collection techniques employed in domains other than road transport was conducted. The error management techniques reviewed were selected based upon their perceived suitability for application within the road transport domain. The following section presents an overview of selected error management and data collection techniques used in other domains including aviation, oil exploration, nuclear power, health care, maritime and rail.

### **3.2.1 Accident Investigation and Analysis**

One of the most obvious means of collecting and analysing error data in complex sociotechnical systems is the retrospective investigation and analysis of accidents and incidents involving operator or human error. Accident investigation is used to reconstruct accidents and identify the human and system contributions, including error, to a particular accident or incident. Accident investigation and analysis allows practitioners to specify exactly what happened and why, and then use the findings to ensure similar accidents do not occur again. In-depth accident analysis studies are also used to identify accident trends. According to Roed-Larsen, Valvisto, Harms-Ringdahl & Kirchsteiger (2004) accident investigation is the most widely used method for clarifying the basic, contributing and immediate causes of accidents and identifying appropriate measures to prevent occurrence of similar events in the future. The following formal definition of accident investigation is offered by the Treasury Board of Canada Secretariat (cited in Harms-Ringdahl, 2004):

*“An accident investigation is the determination of the facts of an accident by inquiry, observation, and examination and an analysis of these facts to establish the causes of the accident and the measures that must be adopted to prevent its recurrence”*

Sklet (2004) suggests that the aim of accident investigations should be the identification of event sequences and all the causal factors influencing an accident scenario so measures to prevent future accidents can be suggested. According to Sklet (2004) the Department of Energy (DOE) divides the accident investigation process into three main phases: the collection of evidence and facts, the analysis of evidence and facts and development of conclusions, and the development of judgements and need in writing the report. The Centre for Chemical Process Safety (CCPS; cited in Sklet, 2004) describes three main purposes of accident investigation techniques as follows:

1. Organisation of information regarding the accident under analysis;
2. Describing accident causation and developing hypotheses for further examination; and
3. The assessment of proposed corrective actions.

There is a plethora of different accident investigation and analysis techniques available. For example, in a review and comparison of accident investigation methods Sklet (2004) selected the following accident investigation methods for comparison: Events and Causal Factors Charting and Analysis; Barrier Analysis; Change Analysis; Root Cause Analysis; Fault Tree Analysis; Influence Diagrams; Event Tree Analysis; Management and Oversight Risk Tree (MORT); Systematic Cause Analysis Technique (SCAT); Sequential Timed Events Plotting (STEP); Man, Technology and Organisation (MTO) analysis; The Accident Evolution and Barrier Function



(AEB) method; TRIPOD; and Acci-Maps. Our literature review identified over 30 accident and analysis-related methods although it is beyond the scope of this report to provide a description of each. However, a number of accident investigation and analysis techniques were selected on the basis of their suitability to road transport to provide an overview of the various different approaches employed in other safety-critical domains. These are the Human Factors Analysis and Classification System (Wiegmann & Shappell, 2003), the Incident Cause Analysis Method (ICAM), the Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACER; Shorrock & Kirwan, 2002), Fault Tree Analysis and Acci-Maps (Svedung & Rasmussen, 2002). A description of the different approaches is provided below.

## **The Human Factors Analysis and Classification System**

Wiegmann & Shappell (2003) developed the Human Factors Analysis and Classification System (HFACS; Wiegmann & Shappell, 2003) for use in aviation accident and incident investigation. According to Wiegmann & Shappell (2003) HFACS was specifically developed to define the latent failures and active errors described in Reason's systems perspective model so that it could be used as an accident investigation and analysis tool. Originally developed for the US Navy and Marine Corps, HFACS is an accident investigation tool that offers a comprehensive framework for analysing aviation incidents involving human error and latent conditions. HFACS was developed from the analysis of hundreds of accident reports containing thousands of human causal factors (Wiegmann & Shappell, 2003). HFACS uses the following four levels of failure: unsafe acts; preconditions for unsafe acts; unsafe supervision; and organisational influences. An error taxonomy is provided for each of the four failure levels. A brief description of each of the levels and their associated error taxonomies is given below.

1. *Unsafe acts.* The first level of HFACS (working backwards from an accident) describes the unsafe acts or errors made by operators that led to the accident in question (i.e. pilot or aircrew error). These are classified into two categories: *errors* and *violations*. Errors refer to those activities performed by operators within the system that result in an undesired outcome. Within the errors category the following three basic error types are defined: skill-based errors; decision errors; and perceptual errors. Skill-based errors are those errors that occur during skill-based behaviour. Skill-based behaviour occurs during routine situations that require highly practiced and automatic behaviour and where there is little conscious control by the operator. Decision errors are those where an inadequate or inappropriate plan is executed correctly. Perceptual errors are those that involve errors in perception. According to Wiegmann & Shappell (2003) perceptual errors typically occur when sensory input is either degraded or unusual. The violations category of unsafe acts refers to those behaviours that deviate from accepted procedures, standards and rules. The violations category is further divided into *routine violations* and *exceptional violations*. Routine violations are those that are habitual and intended by the actor, and are typically tolerated by the relevant authorities (Wiegmann & Shappell, 2003). Routine violations are those occasions when agents 'bend the rules' in order to achieve a particular task. Wiegmann & Shappell (2003) cite the pilot who routinely flies in marginal weather when authorised for visual flight rules only as an example of a routine violation. Exceptional violations are non-habitual, unacceptable and are exceptional in relation to the operators normal behaviour (i.e. they appear uncharacteristic). Wiegmann & Shappell (2003) cite the example of a pilot flying under a bridge as an example

of an exceptional violation. The HFACS unsafe acts categories are presented in Figure 3.1. Examples of the unsafe acts error modes are presented in Table 3.1.

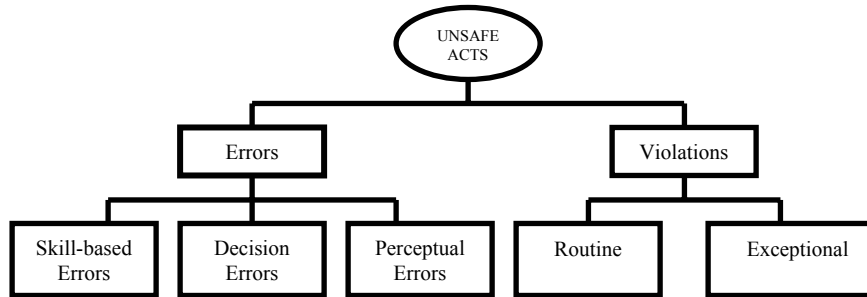


Figure 3.1. Unsafe acts categories (adapted from Wiegmann & Shappell, 2003).

Table 3.1. Extract of unsafe acts taxonomy (adapted from Wiegmann & Shappell, 2003).

ERRORS	VIOLATIONS
<p><b><i>Skill-based Errors</i></b></p> <ul style="list-style-type: none"> <li>• Breakdown in visual scan</li> <li>• Inadvertent use of flight controls</li> <li>• Poor technique/airmanship</li> <li>• Over-controlled the aircraft</li> <li>• Omitted checklist item</li> <li>• Omitted step in the procedure</li> <li>• Over-reliance on automation</li> <li>• Failed to prioritise attention</li> <li>• Task overload</li> <li>• Negative habit</li> <li>• Failure to see and avoid</li> <li>• Distraction</li> </ul>	<p><b><i>Routine</i></b></p> <ul style="list-style-type: none"> <li>• Inadequate briefing for flight</li> <li>• Failed to use ATC radar advisories</li> <li>• Flew an unauthorised approach</li> <li>• Violated training rules</li> <li>• Filed VFR in marginal weather conditions</li> <li>• Failed to comply with departmental manuals</li> <li>• Violation of orders, regulations, SOPS</li> <li>• Failed to inspect aircraft after in-flight caution light</li> </ul>
<p><b><i>Decision Errors</i></b></p> <ul style="list-style-type: none"> <li>• Inappropriate maneuver/procedure</li> <li>• Inadequate knowledge of systems, procedures</li> <li>• Exceeded ability</li> <li>• Wrong response to emergency</li> </ul>	<p><b><i>Exceptional</i></b></p> <ul style="list-style-type: none"> <li>• Performed unauthorized acrobatic maneuver</li> <li>• Improper takeoff technique</li> <li>• Failed to obtain valid weather brief</li> <li>• Exceeded limits of aircraft</li> <li>• Failed to complete performance computations for flight</li> <li>• Accepted unnecessary hazard</li> <li>• Not current/qualified for flight</li> <li>• Unauthorised low-altitude canyon running</li> </ul>
<p><b><i>Perceptual Errors</i></b></p> <ul style="list-style-type: none"> <li>• Due to visual illusion</li> <li>• Due to spatial disorientation/vertigo</li> <li>• Due to misjudged distance, altitude, airspeed, clearance</li> </ul>	

2. *Preconditions for unsafe acts.* Preconditions for unsafe acts refer to the underlying latent conditions that contribute to the occurrence of unsafe acts. The preconditions for unsafe acts category comprises the following three categories: conditions of operators; environmental factors; and personnel factors. The condition of individual operators within complex systems ultimately influences task performance. Operators who are fatigued, stressed, ill or incapacitated may not be able to achieve optimal levels of performance. The conditions of operators category includes adverse mental states (e.g. distraction, mental fatigue, loss of situational awareness), adverse physiological states (impaired physiological state, medical illness, physical fatigue) and physical/mental limitations (insufficient reaction time, visual limitation, incompatible physical capability). The environmental factors category includes physical environment factors (e.g. weather, lighting) and technological environment factors (e.g. equipment/control design, automation). The personnel factors category includes crew resource management factors (e.g. lack of teamwork, failure of leadership) and personnel readiness factors (e.g. inadequate training, poor dietary practice). The categories of preconditions for unsafe acts are presented in Figure 3.2. An extract from the preconditions of unsafe acts taxonomy is presented in Table 3.2.

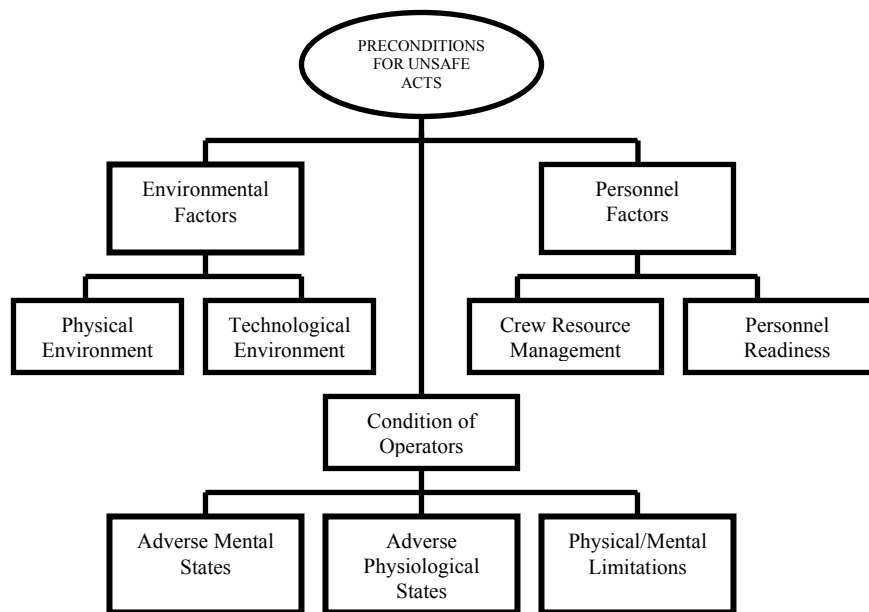


Figure 3.2. Preconditions for unsafe acts categories (adapted from Wiegmann & Shappell, 2003).

Table 3.2. Extract of preconditions of unsafe acts taxonomy (adapted from Wiegmann & Shappell, 2003).

CONDITION OF OPERATOR	PERSONNEL FACTORS
<p><b><i>Adverse Mental States</i></b></p> <ul style="list-style-type: none"> <li>• Loss of situational awareness</li> <li>• Complacency</li> <li>• Stress</li> <li>• Overconfidence</li> <li>• Poor flight vigilance</li> <li>• Task saturation</li> <li>• Alertness (drowsiness)</li> <li>• Get-home-itis</li> <li>• Mental fatigue</li> <li>• Circadian dysrhythmia</li> <li>• Channelised attention</li> <li>• Distraction</li> </ul> <p><b><i>Adverse Physiological States</i></b></p> <ul style="list-style-type: none"> <li>• Medical illness</li> <li>• Hypoxia</li> <li>• Physical fatigue</li> <li>• Intoxication</li> <li>• Motion sickness</li> <li>• Effects of OTC medications</li> </ul> <p><b><i>Physical/Mental Limitations</i></b></p> <ul style="list-style-type: none"> <li>• Visual limitations</li> <li>• Insufficient reaction time</li> <li>• Information overload</li> <li>• Inadequate experience for complexity of situation</li> <li>• Incompatible physical capabilities</li> <li>• Lack of aptitude to fly</li> <li>• Lack of sensory input</li> </ul>	<p><b><i>Crew Resource Management</i></b></p> <ul style="list-style-type: none"> <li>• Failed to conduct adequate brief</li> <li>• Lack of teamwork</li> <li>• Lack of assertiveness</li> <li>• Poor communication/co-ordination within and between aircraft, ATC, etc.</li> <li>• Misinterpretation of traffic calls</li> <li>• Failure of leadership</li> </ul> <p><b><i>Personnel Readiness</i></b></p> <ul style="list-style-type: none"> <li>• Failure to adhere to crew rest requirements</li> <li>• Inadequate training</li> <li>• Self-medicating</li> <li>• Overexertion while off duty</li> <li>• Poor dietary practices</li> <li>• Pattern of poor risk judgement</li> </ul> <p><b>ENVIRONMENTAL FACTORS</b></p> <p><b><i>Physical Environment</i></b></p> <ul style="list-style-type: none"> <li>• Weather</li> <li>• Altitude</li> <li>• Terrain</li> <li>• Lighting</li> <li>• Vibration</li> <li>• Toxins in the cockpit</li> </ul> <p><b><i>Technological Environment</i></b></p> <ul style="list-style-type: none"> <li>• Equipment/controls design</li> <li>• Checklist layout</li> <li>• Display/Interface characteristics</li> <li>• Automation</li> </ul>

3. *Unsafe supervision.* According to Wiegmann & Shappell (2003) the role of any supervisor is to provide their personnel with the opportunity to succeed, and this is achieved through the provision of guidance, training, leadership, oversight, and incentives. Supervisors influence the operational conditions under which operators work, and also the way in which activity is performed. The third level of failure within HFACS, unsafe supervision, considers those instances where supervision is either lacking or inappropriate. The unsafe supervision category is further divided into four categories: inadequate supervision; planned inappropriate operations; failure to correct a known problem; and supervisory violations. Inadequate

supervision refers to those instances when efficient supervision was not provided. Examples of inadequate supervision include ‘failed to provide proper training’, ‘failed to provide professional guidance/oversight’, and ‘failed to provide adequate rest period’. According to Wiegmann & Shappell (2003), planned inappropriate operations refer to those instances where the operational tempo and/or scheduling of aircrew puts individuals at unacceptable risk, jeopardises crew rest and affects performance. Examples of planned inappropriate operations include ‘poor crew pairing’ and ‘failed to provide adequate opportunity for crew rest’. The category failure to correct a known problem refers to those instances when a supervisor is aware of inadequacies within the system, such as inadequate equipment, training or individuals, but does not attempt to rectify the problem. Examples of “failure to correct a known problem” error modes include ‘failed to correct inappropriate behaviour/identify risky behaviour’ and ‘failed to report unsafe tendencies’. The supervisory violations category refers to those instances when rules and regulations are willfully disregarded by supervisors (Wiegmann & Shappell, 2003). Examples of supervisory violations include ‘authorised unqualified crew flight’ and ‘violated procedures’. The unsafe supervision categories are presented in Figure 3.3. Extracts from the unsafe supervision taxonomy are presented in Table 3.3.

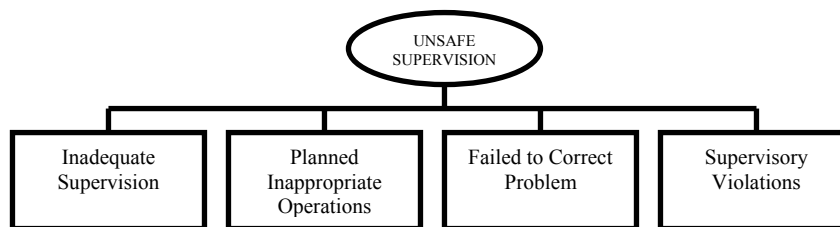


Figure 3.3. Unsafe supervision categories (adapted from Wiegmann & Shappell, 2003).

Table 3.3. Unsafe supervision examples (adapted from Wiegmann & Shappell, 2003).

<b>Unsafe Supervision</b>	
<p><b><i>Inadequate supervision</i></b></p> <ul style="list-style-type: none"> <li>• Failed to provide proper training</li> <li>• Failed to provide professional guidance/oversight</li> <li>• Failed to provide current publications/adequate technical data and/or procedures</li> <li>• Failed to provide adequate rest period</li> <li>• Lack of accountability</li> <li>• Perceived lack of authority</li> <li>• Failed to track qualifications</li> <li>• Failed to track performance</li> <li>• Failed to provide operational doctrine</li> <li>• Over-tasked/untrained supervisor</li> <li>• Loss of supervisory situational awareness</li> </ul>	<p><b><i>Failed to Correct a Known Problem</i></b></p> <ul style="list-style-type: none"> <li>• Failed to correct inappropriate behaviour/identify risky behaviour</li> <li>• Failed to correct a safety hazard</li> <li>• Failed to initiate corrective action</li> <li>• Failed to report unsafe tendencies</li> </ul> <p><b><i>Supervisory Violations</i></b></p> <ul style="list-style-type: none"> <li>• Authorised unqualified crew for flight</li> <li>• Failed to enforce rules and regulations</li> <li>• Violated procedures</li> <li>• Authorised unnecessary hazard</li> <li>• Willful disregard for authority by supervisors</li> <li>• Inadequate documentation</li> <li>• Fraudulent documentation</li> </ul>
<p><b><i>Planned Inappropriate Operations</i></b></p> <ul style="list-style-type: none"> <li>• Poor crew pairing</li> <li>• Failed to provide adequate brief time/supervision</li> <li>• Risk outweighs benefit</li> <li>• Failed to provide adequate opportunity for crew rest</li> <li>• Excessive tasking/workload</li> </ul>	

4. *Organisational influences.* The final category of failure, organisational influences, addresses the fallible decisions made at board and management levels. The HFACS uses three categories of organisational influence failures: resource management (e.g. staffing/manning, excessive cost cutting, poor design); organisational climate (e.g. structure, policies and culture); and organisational process (e.g. time pressure, instructions, risk management). The organisational influences categories are presented in figure 3.4. Examples of organisational influence failures are presented in Table 3.4.

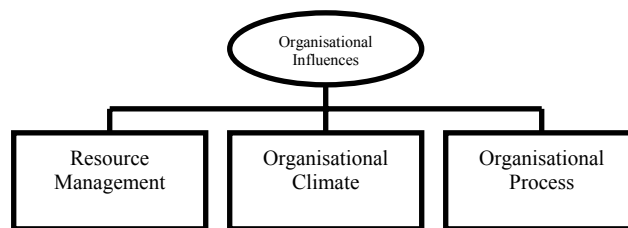


Figure 3.4. Organisational influences categories (adapted from Wiegmann & Shappell, 2003).

Table 3.4. Organisational influences extract (adapted from Wiegmann & Shappell, 2003).

<b>Organisational Influences</b>	
<p><b><i>Resource Management</i></b></p> <p><i>Human Resources</i></p> <ul style="list-style-type: none"> <li>• Selection</li> <li>• Staffing/manning</li> <li>• Training</li> <li>• Background checks</li> </ul> <p><i>Monetry/Budget Resources</i></p> <ul style="list-style-type: none"> <li>• Excessive cost cutting</li> <li>• Lack of funding</li> </ul> <p><i>Equipment/Facility Resources</i></p> <ul style="list-style-type: none"> <li>• Poor aircraft/aircraft cockpit</li> <li>• Purchasing of unsuitable equipment</li> <li>• Failure to correct known design flaws</li> </ul> <p><b><i>Organisational Climate</i></b></p> <p><i>Structure</i></p> <ul style="list-style-type: none"> <li>• Chain of command</li> <li>• Communication</li> <li>• Accessibility/visibility of supervisor</li> <li>• Delegation of authority</li> <li>• Formal accountability for actions</li> </ul> <p><i>Policies</i></p> <ul style="list-style-type: none"> <li>• Promotion</li> <li>• Hiring, firing, retention</li> <li>• Drugs and alcohol</li> <li>• Accident investigations</li> </ul> <p><i>Culture</i></p> <ul style="list-style-type: none"> <li>• Norms and rules</li> <li>• Organisational customs</li> <li>• Values, beliefs, attitudes</li> </ul>	<p><b><i>Organisational Process</i></b></p> <p><i>Operations</i></p> <ul style="list-style-type: none"> <li>• Failed to correct inappropriate behaviour/identify risky behaviour</li> <li>• Failed to correct a safety hazard</li> <li>• Failed to initiate corrective action</li> <li>• Failed to report unsafe tendencies</li> </ul> <p><i>Procedures</i></p> <ul style="list-style-type: none"> <li>• Performance standards</li> <li>• Clearly defined objectives</li> <li>• Procedures/instructions about procedures</li> </ul> <p><i>Oversight</i></p> <ul style="list-style-type: none"> <li>• Established safety programs/risk management programs</li> <li>• Management’s monitoring and checking of resources, climate, and processes to ensure a safe work environment</li> </ul>

HFACS is a comprehensive analysis tool that considers both the errors at the ‘sharp end’ of system operation and also the latent conditions involved in a particular incident or accident. HFACS is designed to aid accident investigators in the classification of latent failures and active errors at each of the failure levels proposed by Reason (1990) in the systems perspective model. Investigators use the failure taxonomies at each level to identify the latent failures and active errors that were involved in the accident or incident under analysis. Wiegmann & Shappell (2001) used HFACS to analyse 119 commercial aviation accidents that occurred between January 1990 and December 1996 (from NTSB and FAA accident databases) that were attributable, in part at least, to aircrew error. The 119 accidents analysed yielded 319 causal factors.

According to Wiegmann & Shappell (2001) all 319 of the causal factors were highlighted using the HFACS framework. Additionally, all but two of the HFACS categories (organisational climate and personal readiness) were observed at least once in the accident database. The analysis indicated that at the unsafe acts classification level, skill-based errors were implicated in the greatest number of accidents (approximately 60% of the accidents analysed). The next greatest category was

decision errors, implicated in approximately 29% of the accidents, and then violations of rules and regulations, implicated in 26.9% of the accidents. At the preconditions for unsafe acts classification level, CRM failures were implicated in the greatest percentage of accidents (approximately 29%), followed by adverse mental states (13.4%), physical/mental limitations (10.9%) and adverse physiological states (1.7%). At the supervisory and organisational factors classification level, only 16% of the accidents were classified as having any supervisory or organisational involvement. Their conclusion was that the HFACS framework is applicable to the commercial aviation domain (since all of the contributory causal factors involved in the accidents were identified by the HFACS framework). HFACS has since been modified and applied in a number of different domains, including general aviation (Gaur, 2005) and air traffic control (Pape, Wiegmann & Shappell, 2001).

The HFACS approach is attractive for a number of reasons, including its treatment of both the errors and latent conditions involved in a particular accident, and also that it provides analysts with taxonomies of errors and latent conditions for each of the levels of failure. The approach is intuitive and easy to learn and apply, and has had considerable success in a number of studies. Such approaches are limited, however, by the data on which they are based. Often the data being analysed does not contain sufficient detail to permit a reliable and valid analysis. Analysts using techniques such as HFACS often find themselves ‘fitting’ the data to the technique, so the validity of such approaches is sometimes questionable. HFACS also suffers from problems that are typically associated with all accident analysis techniques, such as hindsight bias and the attribution of blame to individual operators.

## **TRACEr**

The Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr; Shorrock and Kirwan, 2002) was developed for the retrospective analysis of air traffic management (ATM) incidents in the air traffic control (ATC) domain. As well as being used in the analysis of incidents, TRACEr can also be used pro-actively to predict ATM-related error. The TRACEr approach was developed as part of the Human Error in European Air Traffic Management (HERA) project (Isaac, Shorrock & Kirwan, 2002), which aimed to develop a human error incidence analysis technique. TRACEr uses a series of decision flow diagrams to aid the classification of error and comprises the following eight error-related taxonomies: Task Error, Information; Performance Shaping Factors (PSFs); External Error Modes (EEMs); Internal Error Modes (IEMs); Psychological Error Mechanisms (PEMs); Error detection and error correction. The TRACEr EEM taxonomy is presented in Table 3.5.



Table 3.5. TRACER EEM Taxonomy (Source: Shorrock & Kirwan, 2002).

Selection and Quality	Timing and Sequence	Communication
Omission	Action too long	Unclear Info transmitted
Action Too much	Action too short	Unclear info recorded
Action Too little	Action too early	Info not sought/obtained
Action in wrong direction	Action too late	Info not transmitted
Wrong action on right object	Action repeated	Info not recorded
Right action on wrong object	Mis-ordering	Incomplete info transmitted
Wrong action on wrong object		Incomplete info recorded
Extraneous act		Incorrect info transmitted
		Incorrect info recorded

The TRACER procedure involves classifying events into task errors (e.g. radar monitoring error), and then identifying and classifying any associated internal error modes associated with the error. IEMs describe which cognitive function failed or could fail (Shorrock & Kirwan, 2002). Examples of TRACER IEMs include *late detection, misidentification, hearback error, forget previous actions, prospective memory failure, misrecall stored information and misprojection*. Next, any associated psychological causes or PEMs are identified. Example TRACER PEMs include *insufficient learning, expectation bias, false assumption, perceptual confusion, memory block, vigilance failure and distraction*. Any PSFs that may have contributed to the error are identified using the TRACER PSF taxonomy. An extract from the TRACER PSF taxonomy is presented in Table 3.6.

Table 3.6. Extract from TRACER’s PSF taxonomy (Source: Shorrock & Kirwan, 2000).

PSF Category	Example PSF keyword
Traffic and Airspace	Traffic complexity
Pilot/controller communications	RT Workload
Procedures	Accuracy
Training and experience	Task familiarity
Workplace design, HMI and equipment factors	Radar display
Ambient environment	Noise
Personal factors	Alertness/fatigue
Social and team factors	Handover/takeover
Organisational factors	Conditions of work

Finally, the analyst uses a series of error detection and correction prompts to identify any error detection and correction strategies for the error under analysis. The TRACER approach is appealing as it can be used to comprehensively analyse the errors involved in a particular incident. A number of factors associated with the errors under analysis are considered including the IEMs, PEMs, EEMs and PSFs, and error detection and correction strategies are specified. However, the

comprehensive nature of the approach ensures that it is time-consuming and complicated to apply.

### Fault Tree Analysis

Fault tree analysis is used to graphically represent accident or failure scenarios. Most commonly used for PSA purposes in the nuclear power domain, fault trees are tree-like diagrams which define failure events and display the possible causes of an accident in terms of hardware failure or human error (Kirwan & Ainsworth, 1992). Fault trees use AND and OR gates to link events in an accident sequence. AND gates are used when more than one event causes a failure (i.e. when multiple contributory factors are involved). The events placed directly underneath an AND gate must occur together for the failure event above to occur. OR gates are used when the failure event could be caused by more than one contributory event in isolation, but not together. The event above the OR gate may occur if any one of the events below the OR gate occurs. Bradley (1995) used fault trees to analyse a number of high profile catastrophes in which human error was implicated as a causal factor, including the Titanic shipping disaster, the Flixborough petrochemical disaster, the Three Mile Island, Bhopal and Chernobyl nuclear power disasters, the challenger space disaster and the Erebus and Helderberg air disasters. Bradley's fault tree for the Challenger space disaster is presented in figure 3.5.

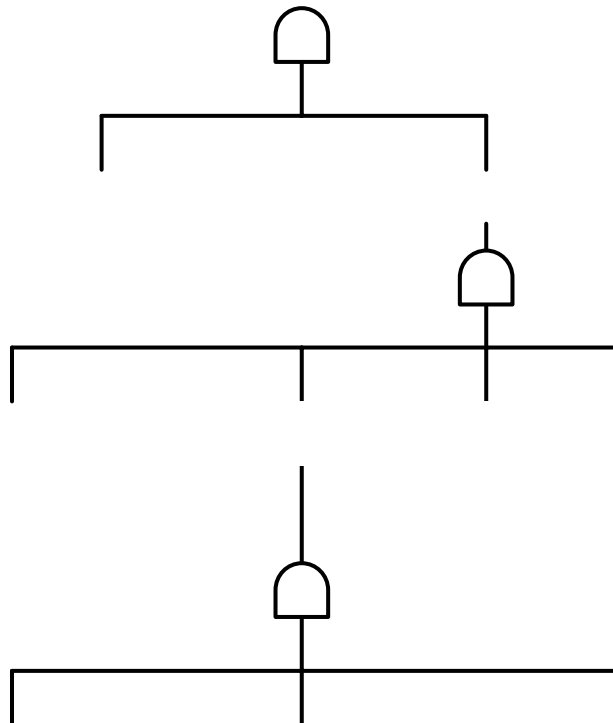


Figure 3.5. Fault tree of Challenger disaster (Source: Bradley, 1995).

## AcciMaps

AcciMapping (Svedung & Rasmussen, 2002) is an accident analysis technique that is used to graphically represent the causal factors involved in a particular accident scenario. The AcciMap differs from typical accident analysis approaches in that, rather than identifying and apportioning blame, it is used to identify and represent the causal flow of events and the planning, management and regulatory bodies that may have contributed to the scenario (Svedung & Rasmussen, 2002) with a view to improving system design and safety. A typical AcciMap comprises the following six main levels: government policy and budgeting; regulatory bodies and associations; local area government planning & budgeting (including company management, technical and operational management; physical processes and actor activities; and equipment and surroundings).

Starting from the bottom of the graph, the equipment and surroundings level provides a description of the accident scene in terms of the configuration and physical characteristics of the landscape, buildings, equipment, tools, and vehicles involved. The physical processes and actor activities level provides a description of the causal and functional relations of the dynamic flow using the cause/consequence chart method. The remaining levels above the physical processes level represent all of the decision makers that, in the course of the decision making involved in their normal work context, did or could have influenced the accident flow during the first two levels. AcciMaps were proposed by Svedung & Rasmussen (2002) to serve the following aims: the analysis of past accidents; the identification of decision makers who have the potential to improve safety; and communication with other disciplines to promote cross-disciplinary co-operation in research and design. Svedung & Rasmussen (2002) present an AcciMap analysis of a transportation of hazardous goods accident scenario. The accident involved a truck carrying 30 tons of 'green' diesel oil which tipped over and collided with a roadside boulder, resulting in a significant oil spill. The Acci-Map for the oil spill accident scenario is presented in Figure 3.6.

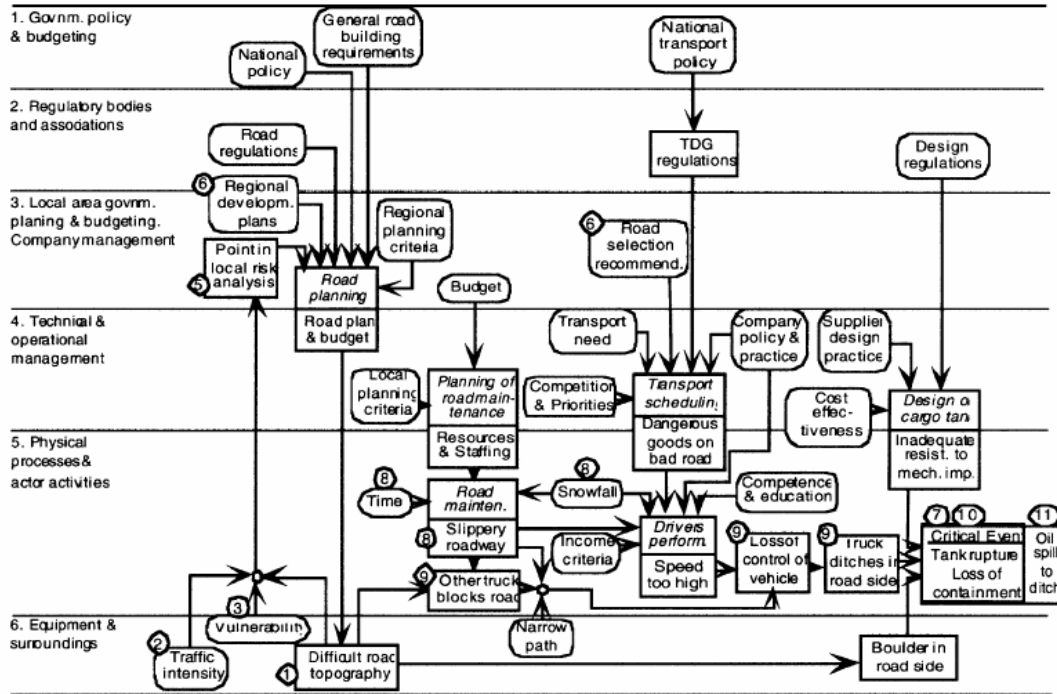


Figure 3.6. AcciMap for hazardous goods accident scenario (Source: Svedung & Rasmussen, 2002).

### The Incident Cause Analysis Method

The Incident Cause Analysis Method (ICAM, BHP Billiton, 2001) is another accident and incident investigation tool that is based upon the principles of Reason’s systems perspective model of accident causation in complex systems. ICAM was developed in 1999 by BHP Billiton and provides a framework for retrospectively analysing accidents and incidents. The ICAM approach uses a model of the different levels within an organisational system, similar to the HFACS approach and Reason’s model of accident causation in complex systems. The ICAM approach is used to identify contributory conditions, actions and deficiencies at the following five levels within a system:

- people;
- environment;
- equipment;
- procedures; and
- organisation.

The ICAM model is presented in Figure 3.7 (Source: BHP Billiton, 2001).

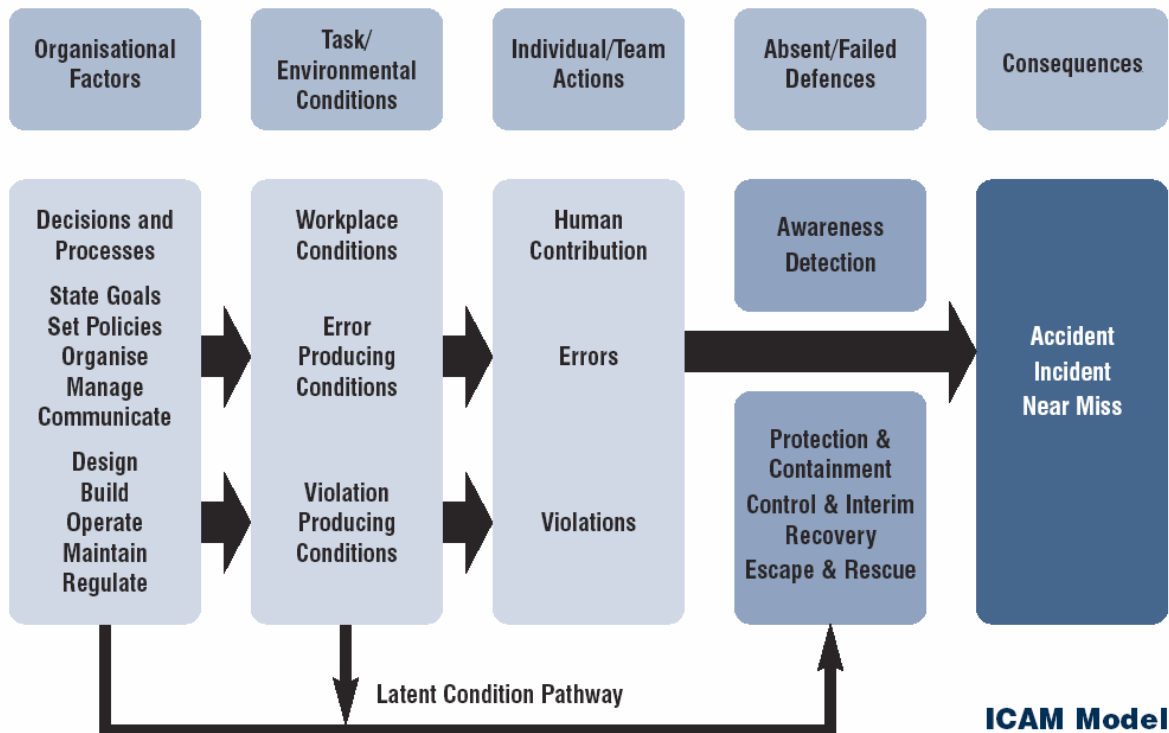


Figure 3.7. ICAM model (Source: BHP Billiton, 2001).

Working backwards from the incident under analysis, the analyst uses the ICAM model to classify the various factors surrounding the incident in question. The first stage involves classifying the facts from the incident report into one of the following five contributory levels: non-contributory acts; absent or failed defences; individual/Team actions; task/Environmental conditions; and organisational factors. The ICAM analysis then proceeds with the identification of the failures at each of the levels described above. A brief description of the failures at each level is presented below.

1. Absent or failed defences. These represent the absence or failure of defences in protecting the system against human and technical failure.

2. Individual/team actions. Individual and team action failures refer to those errors and violations committed by operators within the system that led to the incident in question. This classification is similar to the unsafe acts classification used in Reasons system perspective model and also in the HFACS approach. The ICAM approach uses Reason's taxonomy of unsafe acts discussed in Section 2.3, which considers the following error types:

- slips e.g. attention failures, omissions, mis-ordering etc;
- lapses e.g. Memory failure, Losing place, omitting items etc;
- mistakes e.g. Rule-based and Knowledge-based; and
- violations e.g. Routine, Exceptional and Acts of Sabotage.

3. Task/environmental conditions. The task and environmental level of failure refers to the task and environmental conditions immediately prior to or at the time of the incident that directly influenced human and equipment performance during the incident in question. The ICAM model defines two groups of task and environmental conditions: workplace factors and human factors. The ICAM model provides a series of conditions or factors for each group. Extracts of these factors are presented in Tables 3.7 and 3.8 (Source: BHP Billiton, 2001).

Table 3.7. Workplace factors (Source: BHP Billiton, 2001).

<b>Workplace Factors</b>		
<b>Error Factors</b>	<b>Common Factors</b>	<b>Violation Factors</b>
Change of routine	Time shortage	Violations tolerated
Negative transfer	Inadequate tools and equipment	Compliance goes unrewarded
Poor signal/noise ratio	Poor procedures and instructions	Procedures protect the system not the individual
Poor man/system interface	Poor tasking	Little or no autonomy
Designer/user mismatch	Inadequate training	Macho culture
Educational mismatch	Hazards not identified	Perceived licence to bend rules
Hostile environment	Undermanning	Adversarial industrial climate
Domestic problems	Inadequate supervision	Low operator pay
Poor communications	Poor access to job	Low operator status
Poor mix of hands-on work and written instruction (reliance on undocumented knowledge)	Poor housekeeping	Unfair management sanctions
Poor shift patterns/overtime working	Poor supervisor/worker ratio	Blame culture
	Poor working conditions	Poor supervisory example
	Inadequate mix of experience/inexperienced workers	Task allows for easy short-cuts

Table 3.8. Human factors (Source: BHP Billiton, 2001).

<b>Human Factors</b>		
<b>Error Factors</b>	<b>Common Factors</b>	<b>Violation Factors</b>
Preoccupation, distraction	Insufficient ability	Age and gender
Memory failures	Inadequate skill	High risk target
Strong motor programmes	Skill overcomes danger	Behavioural beliefs (gains > risks)
Perceptual set	Unfamiliarity with task	Subjective norms condoning violations
False sensations	Poor judgement: illusion of control or least effort	Personality: unstable extrovert, non-compliant
False perceptions	Overconfidence	Perceived behavioural control
Confirmation bias	Performance anxiety	Low morale
Situational awareness	Time pressure	Bad mood
Incomplete knowledge	Arousal state: monotony and boredom, emotional status	Job dissatisfaction
Inaccurate knowledge		Attitude to the system
Inference and reasoning		Misperception of hazards

Stress and fatigue		Low self-esteem
Disturbed sleep patterns		Learned helplessness
Error proneness		

4. Organisational factors. The organisational factors level of failure considers those organisational factors that produce conditions that might affect performance in the workplace (i.e. the latent conditions level referred to in Reasons systems perspective model). The ICAM approach uses the following different organisational factor types: hardware; training; organisation; communication; incompatible goals; procedures; maintenance management; design; risk management; management of change, and contractor management. An example ICAM analysis output for an incident involving a truck crane driver who was electrocuted when operating near overhead power lines is presented in figure 3.8 (Source: BHP Billiton, 2001).

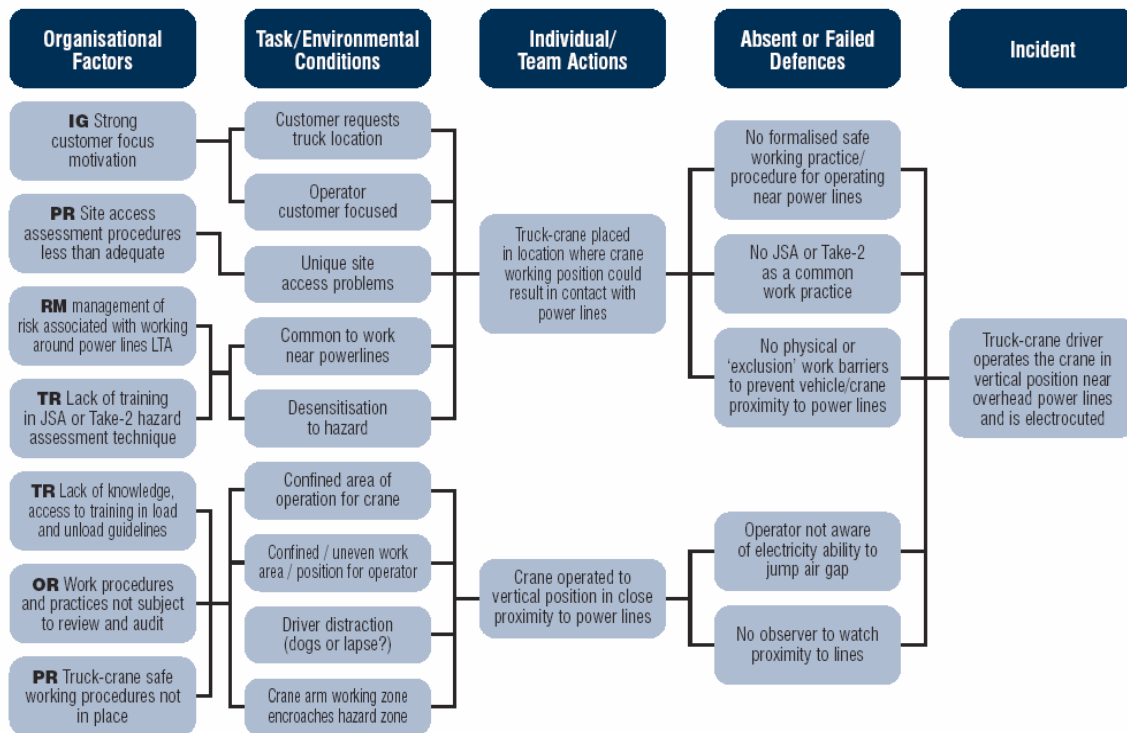


Figure 3.8. ICAM chart for crane incident (Source: (BHP Billiton, 2001).

Once the various contributory factors involved in the incident under analysis are determined, the analyst then proposes corrective actions or remedial measures designed to prevent the occurrence of similar incidents. According to the ICAM model this is best achieved by addressing all of the failure modes identified during the analysis. The ICAMS approach uses the SMARTER acronym for the corrective actions component; that is, that corrective actions proposes should be **S**pecific, **M**easurable, **A**ccountable, **R**easonable, **T**imely, **E**ffective and **R**eviewed. Corrective actions are based upon a hierarchy of controls proposed by the ICAM approach. The ICAM approach also provides an Impact Assessment Matrix, which acts as a guide for analysts during the development of recommendations for corrective actions.

## Summary

Accident investigation and analysis techniques offer a structured approach to the analysis of accident and human error-related data. Various techniques are available for accident analysis and investigation purposes. Accident analysis and investigation is attractive for a number of reasons:

- hindsight ensures that investigators know more about the accident than those that were caught up in it (Dekker, 2002);
- the entire sequence of events is exposed, including triggering conditions, outcome, and the various twists and turns involved (Dekker, 2002);
- it permits an exhaustive analysis of the errors involved, including the contributory factors, nature and associated consequences;
- it permits the identification of the human and systemic causal factors involved in a particular accident;
- it permits the identification of system failures or inadequacies, such as bad design, inadequate training, inadequate equipment and poor management etc; and
- the identification of such factors leads to the development of appropriate countermeasures designed to prevent similar errors and accidents from occurring in the future;

However, despite its obvious utility, accident investigation and analysis has a number of problems:

- typical accident analyses lead to the apportioning of blame to the individuals involved;
- hindsight can potentially lead to oversimplified causality and counterfactual reasoning (Dekker, 2002);
- countermeasures are typically aimed at the individual (e.g. increased training) and thus ignore the system wide contributory factors that may have been involved in the accident in question; and
- accurate accident analysis and investigation is entirely dependent upon the availability of accurate and comprehensive data. Such data is not always available, so much of the investigation is based on assumptions, domain knowledge and expertise.

In addition to the problems outlined above, accident analysis and investigation can only cater for those errors and incidents that evolve into actual accidents, and also for which there is an adequate record. In most safety-critical domains (e.g. aviation, nuclear power) accidents are quite rare. Error-related incidents that do not result in full-scale accidents do occur frequently, however, and accident analysis and investigation ‘misses’ this potentially powerful data. Additionally, some accidents and incidents may go unreported for a number of different reasons (low severity, fear of reprisals etc). Consequently, accident analysis and investigation can only cater for the errors that actually lead to full-scale accidents, and this typically represents only a limited sub-set of the types of errors that occur within a particular system. These problems were pointed out by Johnston and Perry (1980) who suggested that when investigating driver behaviour and errors, accidents represent a far from satisfactory criterion due to their rarity, the under-reporting of accidents, and the major systematic biases contained in official accident reports. To counteract such problems, incident or near-miss reporting schemes are used to gather error-related data from incidents that do not actually evolve into full scale accidents.



### 3.2.2 Incident Reporting Systems

Near misses are those hazardous situations, events or unsafe acts that occur where the sequence of events could have caused an accident if it had not been interrupted (Jones, Kirchsteiger & Bjerke, 1999). According to Reason (1997) a near miss is any incident that could potentially have had bad consequences, but did not. Incident or near miss reporting is a well established method of improving safety in complex systems (Koorneef, 2000; cited in Ternov, Tegenrot & Akselsson, 2004). Incident reporting systems are used to collect pertinent information regarding critical incidents (or near misses), error, safety compromising incidents and safety concerns within complex, dynamic or safety-critical systems. Incident reporting systems enable system personnel (i.e. pilots, control room operators, anaesthetists) to report such incidents and safety concerns to the appropriate bodies. Typically, incident reporting systems are confidential, anonymous and non-punitive. The incident data gathered is used for a number of purposes, including enhancing system safety, increasing understanding of safety-related issues and facilitating safety-related research. Incident reporting systems work on the premise that critical incidents or 'near misses' involving error represent warnings or indications of potentially catastrophic accidents. The concept of incident reporting originated within the aviation domain, with the introduction of the Aviation Safety Reporting System (ASRS) in 1975. Incident reporting systems now exist in a wide range of domains, including aviation, air traffic control, health care, rail and the nuclear power domains. However, to the authors' knowledge, there are no such schemes employed in the road transport domain.

#### The Importance of Collecting Near-Miss Data

A number of researchers have highlighted the potential advantages associated with the collection and analysis of near miss data. According to Reason (1997), the collection and analysis of near miss data has a number of advantages, including:

- when the right conclusions are drawn and acted upon, they work like 'vaccines' to mobilise a system's defences against more serious future occurrences;
- they provide a qualitative insight into how small defensive failures can line up to create large disasters;
- as they occur more frequently than actual accidents, they provide the numbers required for more pertinent quantitative analysis; and
- they provide a powerful reminder of the hazards that reside within a particular system.

According to Van der Schaaf (1995), near-misses are more numerous than actual accidents, contain valuable information on system functioning, such as why things did not go wrong in the end, and contain references to safety rules, training and safety equipment defences 'in action'. Jones et al (1999) recommend that the internal investigation of near-misses should be an integral part of safety management systems and should aim to prevent accidents and the occurrence of similar events in the near future. In the past researchers have attempted to quantify the link between near miss-incidents and major accidents within complex, dynamic systems. For example, Bird's near-miss triangle (Figure 3.9) demonstrates that for each major accident, there are a greater number of associated minor accidents and an even greater number of near-misses. Research has

also indicated that reducing the number of near-misses reduces the number of full-blown accidents (by reducing those near-misses that evolve into actual accidents (Jones et al, 1999).

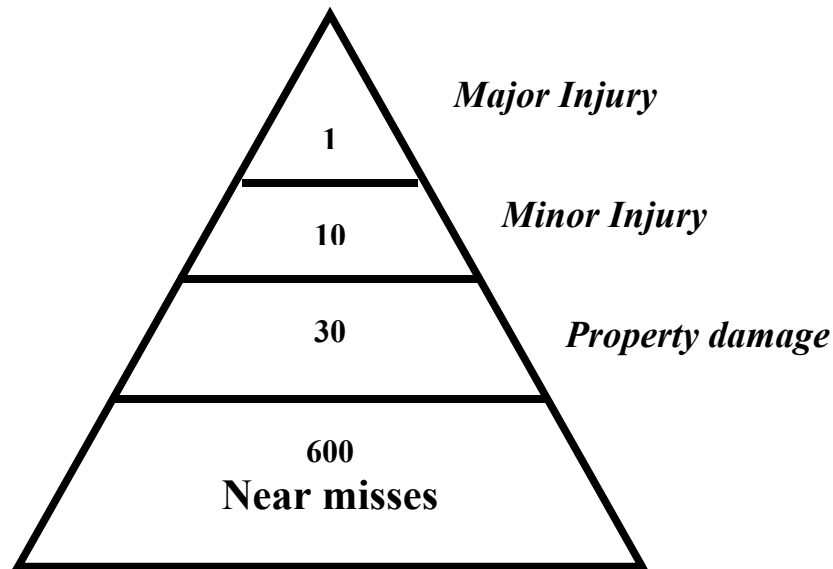


Figure 3.9. Birds accident triangle (adapted from Jones et al, 1999).

Heinrich, Peterson and Roos (1980; cited in Wierwille et al, 2002) also developed a triangle that demonstrates the relationship between near-misses and fatal accidents in industrial settings. Heinrich and colleagues estimate that, for every fatal accident, there are 10,000 associated near accidents or near-miss scenarios. The triangle proposed by Heinrich et al is presented in Figure 3.10.

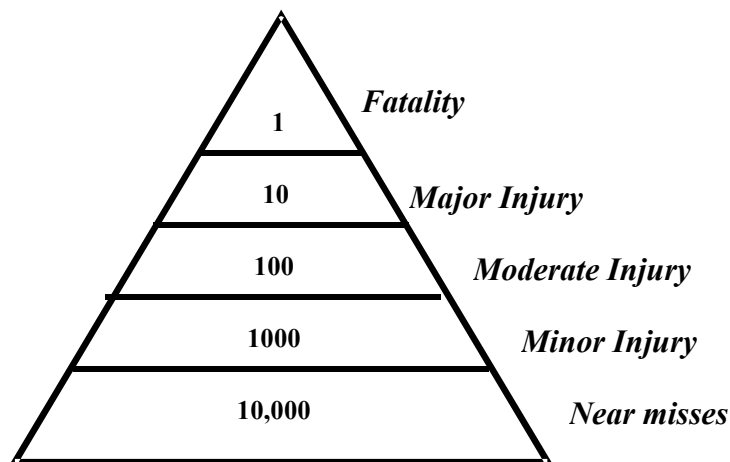


Figure 3.10. Critical incident triangle.

Dingus, McGhee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman (1995; cited in Wierwille, et al, 2002) applied Hienrich's triangle in the road transport domain to investigate the estimation of road transport injury accidents. On the basis of road accident, injury accident, and non-injury accident data, Dingus and colleagues calculated that, for every accident involving a fatality, there are approximately 100,000 errors with a hazard present and 1,000,000 errors with no hazard present.

The following section provides a brief overview of selected incident reporting schemes that are currently employed within the aviation, health-care, and nuclear power domains.

## Aviation

Incident reporting systems were first introduced in the aviation domain. Probably the most well known incident reporting system is the Aviation Safety Reporting System (ASRS) used by the U.S. FAA and NASA. The ASRS was established in 1975, and is used to collect, analyse and respond to aviation safety incident reports in order to reduce the likelihood of aviation accidents. The ASRS was introduced in response to an investigation into a major controlled flight into terrain (CFIT) incident which revealed that similar incidents had previously occurred but had not been reported to the appropriate bodies. The ASRS permits anyone involved in aviation operations, including pilots, air traffic controllers, flight attendants, mechanics and ground personnel, to submit reports describing incidents in which aviation safety was compromised in any way. Reports are submitted voluntarily and anonymously, and are treated confidentially. Incidents are reported via ASRS incident report forms. Once submitted, ASRS reports are analysed by at least two aviation safety analysts. Initially, any aviation hazards are identified from the report. If any hazards are identified, an alerting message is sent to the appropriate aviation authority. Next, the reports are classified in terms of the incident's underlying causes. The report and associated findings are then added to the ASRS database. According to the ASRS website, the information received through the ASRS is used for the following purposes:

- alerting messages. When the ASRS receives reports containing reference to a 'hazardous' situation, an alerting message is issued. Alerting messages are used to relay safety information to individuals in a position of authority so that hazardous incidents can be investigated and appropriate measures can be taken;
- callback. Callback is a monthly safety bulletin distributed to aviation personnel (pilots, air traffic controllers, mechanics etc) by the ASRS. Callback contains extracts from ASRS incident reports and summaries of ASRS research and aviation safety information;
- ASRS Directline. ASRS Directline is an additional publication that contains articles based on significant ASRS reports. ASRS Directline is distributed to operational managers, safety officers, training organisations and publications departments;
- database search requests. The information in the ASRS database can be accessed on request;
- operational support. The ASRS uses the information in its database to support the FAA and NTSB in rule making, procedural design, airspace design, and accident investigation; and
- topical research. The ASRS is also actively involved in the conduct of aviation safety-related research and has conducted and published over 56 research studies.

To date, the ASRS has received over 600,000 reports and its success is such that most other incident reporting systems in the aviation domain and elsewhere are based upon its principles.

The UK Confidential Human Factors Incident Reporting Programme (CHIRP) is based on the ASRS and is used to gather and analyse aviation safety-related reports from the UK aviation sector. CHIRP was established in 1982 as a result of a joint initiative between the Civil Aviation Authority (CAA) and the Institute of Aviation Medicine (IAM). According to the CHIRP website ([www.chirp.co.uk](http://www.chirp.co.uk)), CHIRP's main objective is to promote safety in the aviation and maritime sector for employees and others by obtaining, distributing and analysing safety-related reports. Similar to the ASRS, CHIRP is a voluntary, confidential and non-punitive system, and reports may be submitted by pilots (general and commercial), cabin crew members, maintenance and engineering staff, and design and production staff. Feedback is provided in the form of the FEEDBACK newsletter, which features summary statistics, de-identified incident reports, remedial suggestions and references to CAA regulations (Beaubien & Baker, 2002). CHIRP provides specific forms for each of the different reporting groups identified above.

In Australia, the Confidential Aviation Incident Reporting (CAIR) system was used between 1988 and 2002. Similar to ASRS and CHIRP, CAIR was a voluntary, confidential and non-punitive system. CAIR has since been replaced by the Aviation Self Reporting System (ASR System), which commenced operation in February 2004. The ASR System is also voluntary, confidential and non-punitive and was introduced following an amendment to the Civil Aviation Act 1988. The ASR scheme allows any civil aviation authorisation holder to report a contravention of the civil aviation regulations 1988 and the civil aviation safety regulations 1998. The ASR scheme aims to use incident reports to strengthen the foundation of aviation human factors safety research, identify deficiencies and problems within the Australian aviation safety system, and provide data for planning and improvement to the Australian aviation safety system.

## Health Care

Numerous incident reporting systems have also been implemented within the health care domain. Various incident reporting systems exist for different health care sectors, including intensive care units (Buckley, Short, Rowbottom & Oh, 1997), anaesthesia (Staender, Davies, Helmreich, Sexton & Kaufmann, 1997), neonatal intensive care (Ahluwalia & Marriot, 2005) and general health care (Takeda, Matsumura, Nakajima, Kuwata, Zhenjun, Shanmai, Qiyang, Yufen, Kusuoka & Inoue, 2003). It is beyond the scope of this document to offer a comprehensive description of every incident reporting system implemented although a brief description of selected schemes is provided below.

### *Anaesthesia*

Critical incident reporting is well established in anaesthesia (Buckley et al, 1997). Inspired by the ASRS used in aviation, Staender, Davies, Helmreich, Sexton and Kaufmann (1997) developed the Critical Incident Reporting System (CIRS) to collect anonymous critical incident reports in anaesthesia to gain insight into the nature of critical events and collect cases that could be used to teach other anaesthetists. The CIRS defines a critical incident as any deviation from an expected course with potential for an adverse outcome (Staender et al, 1997). The CIRS is based in Switzerland and offers an anonymous and confidential internet-based reporting system.

### *Intensive Care*

The Australian Incident Monitoring Study (AIMS) is a national study established to develop, introduce and evaluate an anonymous voluntary incident reporting system for intensive care (Beckmann, Baldwin, Hart & Runcimann, 1996). The AIMS defines an incident as any unintended event or outcome which could have, or did, reduce the safety margin for the patient, and aims to improve quality of care in intensive care units by accumulating experience of incidents that may affect patient safety (Beckmann et al, 1996). The AIMS report form allows the reporter to provide a narrative of the incident, and then uses check boxes to gather information regarding the patient and personnel involved, when and where the incident happened, contributing factors, and factors limiting the effects of the incident. Within that part of the form dealing with the factors contributing to the incident, AIMS uses a knowledge, skill and rule-based error taxonomy to allow the reporter to classify any errors that contributed to the incident.

### *General Health Care*

The US Food and Drug Administration set up the Medwatch system in 1984. MedWatch is a comprehensive reporting system that allows healthcare professionals and consumers to report problems with the drugs and medical devices that they prescribe, dispense, or use. MedWatch allows reports to be submitted online, over the phone or via a MedWatch form. The data collected is used to provide important safety-related information on the MedWatch website regarding medical products, such as prescriptions and medical devices. Safety alerts, recalls, withdrawals and labelling changes are examples of how the information collected is used to enhance safety. Whilst the MedWatch system is confidential, it is not anonymous which allows reporters to be contacted for further information. To date, the Medwatch system has received over 700,000 reports (Johnson, 2002).

### **Nuclear Power**

Within the nuclear processing domain, the Major Accident Reporting System (MARS) was established in 1984 as a result of the 'Seveso I Directive' (Seveso I, 1982; cited in Jones et al, 1999). The MARS is used to gather information regarding 'major accidents' and other events with 'unusual characteristics' (Jones et al, 1999) as defined by the Seveso I Directive. The MARS was recently adapted in accordance with the Seveso II Directive, to allow the reporting of smaller accidents and near miss incidents (Jones et al, 1999).

## **Effectiveness of Incident and Near Miss Reporting Systems**

It is clear that incident reporting schemes provide an effective means of gathering and classifying human error-related data. However, although such schemes are now employed within most safety critical domains, there is only limited information available regarding the success of such schemes. The main reason for this is the difficulty in assessing how effective such schemes are. Although the number of reports received can be used as an indication of the uptake or popularity of such schemes, it is not appropriate for assessing their effectiveness. For example, within the aviation domain the ASRS has to date received over 600,000 incident reports, and in the health care domain the MedWatch program has received over 700,00 reports.

The effectiveness of incident reporting schemes is, however, related to the identification of safety-related issues, the enhancement of safety and the reduction of latent conditions and active errors within the systems in which they are employed. Assessing the effectiveness of such systems is difficult. A reduction in accidents and incidents would seem to be the first thing to look for. However, there is often no way of knowing that accidents and incidents have fallen specifically due to the introduction of an incident reporting schemes. Often there are other factors which contribute to reduced accident occurrence in such systems, such as improved technology, increased training, safety campaigns, and the use of new procedures. This is perhaps why references to the effectiveness of such schemes are so scarce. Jones et al (1999) point out that, within Norsk Hydro offshore facilities, an increased focus on the importance of near-misses led to an increase in reporting which in turn led to a decrease in the number of accidents. When the focus upon near misses was subsequently relaxed, the accident rate increased. Johnson (2002) suggests that, due to their perceived success, incident reporting schemes are playing an increasingly important role in the development and maintenance of safety-critical applications. However, to the authors' knowledge, there are no quantitative estimates of the success of such schemes. While this is disappointing, it is our opinion that this does not negate the use of such systems, and that their many advantages suggest they are a crucial component of error management within complex, dynamic systems.

## Summary

Incident or near miss reporting systems are now a common feature in complex sociotechnical systems. The utility of such systems lies in their ability to generate large amounts of incident or near miss data that would otherwise go un-noticed. This data are useful in that they contain information about incidents or accidents that are, in a sense, waiting to happen. They also contain information regarding the types of errors made, the causes of the errors made, and also recovery strategies for the errors made.

In most safety-critical domains, incident reporting systems have become extremely popular. According to Johnson (2003), incident reporting systems are attractive for the following reasons:

- incident reports help to identify why accidents do not occur;
- the high frequency of incident reports allows for the quantitative analysis of the data;
- incident reports provide a reminder of system-wide hazards;
- feedback derived from incident reports keeps system actors 'in the loop' and encourages agent participation in safety improvement. Operators can see that their concerns are being followed up effectively;
- the data and lessons derived from incident reporting systems can be compared across domains and industries. The identification of common causes can lead to common solutions;
- incident reporting schemes are cheaper to implement than the cost of an accident; and
- in future, incident reporting systems may be required by regulatory agencies as evidence of an appropriate safety culture.

Despite the various advantages associated with the collection of near miss data and the use of incident reporting systems, there are a number of disadvantages that may affect the data collected. The most obvious flaw is the fact that operators will not always report near-miss or critical

incidents. There are a number of reasons for this. Firstly, informants may not wish to admit that they have made an error or contributed to an incident that compromised system safety in any way. According to Reason (1997) persuading people to file critical incident and near miss reports is not an easy task, particularly when it involves divulging their own errors. Secondly, informants may fear of any action that may be taken against them as a result of the incident that they report. To counteract this, most incident reporting schemes are confidential, anonymous and non-punitive. Thirdly, Reason (1997) points out that potential informants often fail to see the value in making reports. Often people are skeptical of such systems, in particular of the data actually being acted upon, and the extra work involved in creating and filing the report puts them off ever doing so. Another flaw concerns the quality of the data collected. The retrospective description of incidents is fraught with problems, including memory degradation (Klein & Armstrong, 2004) and a potential glorification of events. Further, informants may be unable to provide a sufficiently accurate and detailed account of an incident and its associated contributory events (Reason, 1997). Finally, incident reporting systems may suffer from problems associated with the understanding of what it is that actually constitutes a near miss or critical incident. Whilst most pilots would report a gross error such as failing to lower the landing gear, they may not report errors that they perceive to be minor incidents, such as entering the wrong altitude or airspeed into the flight management computer. Such incidents could potentially lead to catastrophes, yet may not be reported due to their (wrongly) perceived insignificance. In addition to the issues described above, Johnson (2002, 2003) points out the following disadvantages associated with the use of incident reporting systems:

- it is difficult to elicit information from actors that are involved in adverse incidents;
- the data obtained are subject to a number of biases, including confidence bias, hindsight bias, judgement bias, political bias and recency bias;
- incident reporting systems are typically expensive to set up and run. The ASRS, for example, spends approximately \$3 million per year analysing around 30,000 reports (Leape, cited in Johnson, 2003);
- there is only limited sharing of data between established incident reporting systems;
- incident reporting systems may fail to keep actors ‘in the loop’;
- incident reporting systems may serve merely as reminders of failures that operators within the system already know exist but do not have the incentive to address;
- incident reporting systems typically recommend only short-term fixes or countermeasures that fail to address the various underlying causes of incidents;
- there have been only limited attempts to ensure consistency in responses to incidents e.g. different countermeasures may be proposed for the same incident in different cultures or countries; and
- incident reporting systems have a tendency to remind actors of their failures rather than address the associated root causes.

Despite these problems, Reason (1997) points out that the success of a number of schemes indicates that the advantages greatly outweigh the flaws. Further, Amalberti (2001) suggests that:

*“Reporting is fundamental to improve safety. Reporting describes the undesirable ‘noise’ plaguing the system in three areas of reference: the tool and its failures; the operator and his failures; and the resulting situation (situational, organisational or systemic failings).” (Amalberti, 2001).*

### **3.2.3 Human Error Identification**

Human Error Identification (HEI) or error prediction offers a pro-active strategy for investigating human error in complex sociotechnical systems. The prediction of human error is used within risk assessments in order to identify potential error occurrence and determine the causal factors, consequences and recovery strategies associated with the errors identified. The error information derived is then typically used to highlight system design flaws, propose remedial design measures, identify procedural deficiencies and to quantify error incidence probabilities. HEI works on the premise that an understanding of an employee’s work task and the characteristics of the technology being used allows us to indicate potential errors that may arise from the resulting interaction (Stanton and Baber, 1996).

The concept of error prediction was first investigated in response to a number of high profile catastrophes attributed to human error in the nuclear and chemical processing domains, such as the Three Mile Island, Bhopal and Chernobyl disasters. The use of HEI techniques is now widespread, with applications in a wide range of domains including the nuclear power and petrochemical processing industry (Kirwan, 1996), air traffic control (Shorrock & Kirwan, 2002), aviation (Marshall et al, 2003), naval operations, military systems, space operations (Nelson et al, 1998), medicine and public technology (Baber & Stanton, 1996). There are a number of diverse HEI techniques available ranging from simple error taxonomy-based techniques, which offer error modes linked to operator behaviours, to more sophisticated error quantification and computational error simulation techniques. HEI techniques can be classified into two groups, qualitative and quantitative. Qualitative HEI techniques are used to predict the different types of errors that may occur, whilst quantitative HEI techniques are used to predict the numerical probability of the different errors occurring. The literature review identified over 50 HEI techniques which were classified into the following categories of HEI technique:

- Taxonomy-based techniques;
- error identifier prompt techniques;
- error quantification techniques;
- cognitive modeling techniques; and
- cognitive simulation techniques.

A brief overview of the different types of HEI techniques is presented below.

#### **Taxonomy-Based Techniques**

Taxonomy-based HEI techniques use EEM taxonomies to identify potential error within complex, sociotechnical systems. Typically EEMs are considered for each component step in a particular task or scenario in order to determine credible errors that may arise during the man-machine interaction. Techniques such as SHERPA (Embrey, 1986), the Human Error Template (HET; Marshall et al, 2003), TRACEr (Shorrock & Kirwan, 2002), and CREAM (Hollnagel, 1998)



all use domain specific EEM taxonomies. Taxonomic approaches to HEI are typically the most successful in terms of sensitivity and are also the cheapest, quickest and easiest to use. However, these techniques depend greatly on the judgement of the analyst and their reliability and validity may at times be questionable. For example, different analysts with different experience may make different error predictions for the same task (inter-analyst reliability). Similarly, the same analyst may make different judgements on different occasions (intra-analyst reliability). To demonstrate how taxonomy-based error prediction is conducted, a brief description of the SHERPA technique is given below.

The SHERPA technique (Embrey, 1986) was originally developed for use in the nuclear reprocessing domain and is probably the most commonly used HEI approach, with applications in a number of other domains including aviation (Salmon, Stanton, Young, Harris, Demagalski, Marshall, Waldmann & Dekker, 2002, 2003), ticket machines (Baber & Stanton, 1996), vending machines (Stanton and Stevenage, 1998), and in-car radio-cassette machines (Stanton & Young, 1999). SHERPA uses an EEM taxonomy linked to a behavioural taxonomy and is applied to a hierarchical task analysis (HTA; Annett, 2004) of the task or scenario under analysis. When conducting a SHERPA analysis, the analyst uses subjective judgement to identify credible errors that might occur during the performance of each bottom level task step in the HTA. Firstly, the analyst takes each bottom level task step (or operation) from the HTA and classifies it as one of the five following behaviour types:

- action – e.g. pressing a button, moving a lever;
- retrieval – e.g. retrieving information from a display;
- check – e.g. making a procedural check;
- selection – e.g. choosing one alternative over another; and
- information communication – e.g. communicating with other agents.

The analyst then uses the associated EEM taxonomy and domain expertise to identify any credible (i.e. those judged by the analyst to be possible) errors for the task step in question. For each credible error the analyst provides a description of the error, such as ‘pilot dials in wrong airspeed’ or ‘operator checks the wrong display’. The SHERPA EEM is presented in Figure 3.11.

**Action Errors**

- A1 - Operation too long/short
- A2 – Operation mistimed
- A3 – Operation in wrong direction
- A4 – Operation too little/much
- A5 – Misalign
- A6 – Right operation on wrong object
- A7 – Wrong operation on right object
- A8 – Operation omitted
- A9 – Operation incomplete
- A10 – Wrong operation on wrong object

**Checking Errors**

- C1 – Check omitted
- C2 – Check incomplete

**Retrieval Errors**

- R1 – Information not obtained
- R2 – Wrong information obtained
- R3 – Information retrieval incomplete

**Communication Errors**

- I1 – Information not communicated
- I2 – Wrong information communicated
- I3 – Information communication

**Selection Errors**

- S1 – Selection omitted
- S2 – Wrong selection

- C3 – Right check on wrong object
- C4 – Wrong check on right object
- C5 – Check mistimed
- C6 – Wrong check on wrong object

Figure 3.11. SHERPA error mode taxonomy.

Next, the analyst determines the consequences associated with the error and any error recovery steps that would need to be taken by the operator in event of the error. Finally, estimates of ordinal probability (low, medium or high) and criticality (low, medium or high) are given and any potential design remedies (i.e. how the interface design could be modified to eradicate the error) are provided. A SHERPA analysis of the flight task ‘Land aircraft X at New Orleans airport using the autoland system’ was conducted to identify potential design-induced pilot error within the cockpit of aircraft X. An extract of the HTA is presented in Figure 3.12 (Source: Harris, Stanton, Marshall, Young, Demagalski & Salmon, 2005). An extract of the SHERPA analysis is presented in Table 3.9 (Source: Harris et al, 2005).

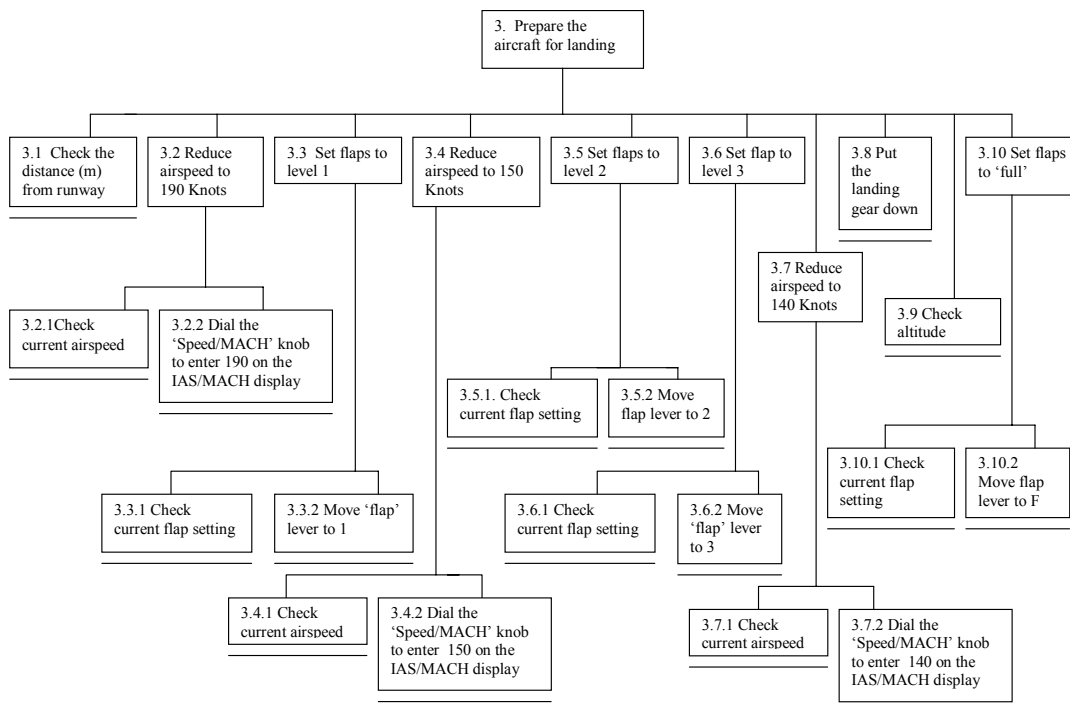


Figure 3.12. Extract of HTA for ‘Land at New Orleans using the autoland system’ (Source: Salmon et al, 2002).

Table 3.9. SHERPA output extract (Source: Harris et al, 2005)

Task Step	Error mode	Description	Consequence	Recovery	P	C	Remedial measures
3.2.2	A3	Pilot turns the Speed/MACH selector knob the wrong way	The wrong airspeed is entered and the plane speeds up instead of slowing down	3.2.1	M	M	- Clearer control labeling - Auditory signal informing increase/decrease
3.2.2	A6	The pilot dials in the desired airspeed using the wrong control knob i.e. the heading knob	Before capture, the auto-pilot will attempt to switch course to the speed value entered causing the plane to leave the glideslope	Immediate	M	H	- Improved control labeling - Improved separation of controls

## Error Identifier Techniques

Error identifier techniques use prompts or questions to aid the analyst in identifying potential errors. Examples of error identifier prompts include ‘Could the operator fail to carry out the act in time?’, ‘Could the operator carry out the task too early?’, and ‘Could the operator carry out the task inadequately?’ (Kirwan, 1994). The prompts are linked to a set of error modes and reduction strategies. Whilst these techniques attempt to remove the reliability problems associated with taxonomy-based approaches, they add considerable time to the analysis because each prompt must be considered. One example of an error identifier HEI technique is the Human Error Identification in Systems Tool approach (HEIST; Kirwan, 1994). A brief description of the HEIST approach is given below.

The HEIST approach uses error prompts to aid the analyst in the identification of operator error and comprises a series of prompts linked to an EEM taxonomy. HEIST uses prompts derived from the following stages of human activity: activation/detection; observation/data collection; identification of system state; interpretation; evaluation; goal selection/task definition; procedure selection and procedure execution. In conducting a HEIST analysis, the analyst first takes a task step from a HTA of the task or scenario under analysis and classifies it into one of the eight behaviour categories identified above. The analyst then uses the associated error prompts to identify potential errors for the task step in question. For each credible error identified, the analyst records the system cause, psychological error mechanism (PEM) and associated error reduction guidelines (all of which are selected from the HEIST behaviour table). The associated error

consequences are then identified and recorded. An extract of a HEIST analysis for the flight task 'Land aircraft X at New Orleans using the autoland system' is presented in Table 3.10.

Table 3.10. Extract of HEIST analysis of the task 'Land at New Orleans using auto-land system' (Salmon, et al 2003).

Task step	Error code	EEM	Description	PEM System cause	Consequence	Error reduction guidelines
3.2.2	PEP3	Action on wrong object	Pilot alters the airspeed using the wrong knob e.g. heading knob	Topographic misorientation Mistakes alternatives Similarity matching	The airspeed is not altered and the heading will change to the value entered	Ergonomic design of controls and displays Training Clear labelling
3.2.2	PEP4	Wrong action	Pilot enters the wrong airspeed	Similarity matching Recognition failure Stereotype takeover Misperception Intrusion	Airspeed will change to the wrong airspeed	Training Ergonomic procedures with checking facilities Prompt system feedback

## Error Quantification Techniques

Error quantification techniques are used to determine numerical probabilities of error occurrence. Potential errors are identified and then a numerical probability value that represents the probability of the error occurring is assigned to each error. PSFs are typically used to aid the analyst in the identification of potential errors. Error quantification techniques are typically used in the probabilistic safety assessment (PSA) of nuclear processing plants. For example, Kirwan (1996) reports the use of JHEDI in a HRA risk assessment for the BNFL Thermal Oxide Reprocessing Plant at Sellafield, and also the use of HEART in a HRA risk assessment of the Sizewell B pressurised water reactor. A brief description of the HEART approach is given below.

The Human Error Assessment and Reduction Technique (HEART; Williams, 1986) was developed specifically for the nuclear power and chemical processing domains, and offers a structured approach for the prediction and quantification of human error. The HEART approach comprises a set of generic task categories, each with an associated human error probability value, a set of error producing conditions (EPCs) and a taxonomy of remedial measures. To conduct a HEART analysis, the analyst takes each step from a HTA of the task under analysis and identifies its proposed nominal level of human unreliability using the HEART generic categories (see Table 3.11). For example, if the analysis was focussed upon a non-routine, emergency situation this would be classified as (A) Totally unfamiliar, performed at speed with no real idea of likely consequences. The associated unreliability probability would be 0.55. Next, the analyst identifies any relevant EPCs that might affect task performance and rates the assessed proportion of effect for each EPC (0 = Low, 1 = High). The HEART EPCs are presented in Table 3.12. Finally,

remedial measures are proposed for each identified error. An example HEART output is presented in Table 3.13 (Source: Kirwan, 1994).

Table 3.11. HEART generic categories (Source: Kirwan, 1994).

<b>Generic Task</b>	<b>Proposed human unreliability (5<sup>th</sup> – 95<sup>th</sup> percentile bounds)</b>
(A) Totally unfamiliar, performed at speed with no real idea of the likely consequences	0.55 (0.35 – 0.97)
(B) Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26 (0.14 – 0.42)
(C) Complex task requiring high level of comprehension and skill	0.16 (0.12 – 0.28)
(D) Fairly simple task performed rapidly or given scant attention	0.09 (0.06 – 0.13)
(E) Routine, highly practised, rapid task involving relatively low level of skill	0.02 (0.007 – 0.045)
(F) Restore or shift a system to original or new state following procedures, with some checking	0.003 (0.0008 – 0.0009)
(G) Completely familiar, well designed, highly practised, routine task occurring several times per hour, performed at the highest possible standards by highly motivated, highly trained and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004 (0.00008 – 0.009)
(H) Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0.00002 (0.000006 – 0.009)

Table 3.12. HEART EPC's (Source: Kirwan, 1994).

<b>Error producing condition (EPC)</b>	<b>Maximum predicted amount by which unreliability might change, going from good conditions to bad</b>
Unfamiliarity with a situation which is potentially important but which only occurs infrequently, or which is novel	<b>X17</b>
A shortage of time available for error detection and correction	<b>X11</b>
A low signal to noise ratio	<b>X10</b>
A means of suppressing or overriding information or features which is too easily accessible	<b>X9</b>
No means of conveying spatial and functional information to operators in a form which they can readily assimilate	<b>X8</b>
A mismatch between an operator's model of the world and that imagined by a designer	<b>X8</b>
No obvious means of reversing an unintended action	<b>X8</b>
A channel capacity overload, particularly one caused by simultaneous presentation of non redundant information	<b>X6</b>
A need to unlearn a technique and apply one which requires the application of an opposing philosophy	<b>X6</b>
The need to transfer specific knowledge from task to task without loss	<b>X5.5</b>
Ambiguity in the required performance standards	<b>X5</b>
A mismatch between perceived and real risk	<b>X4</b>
Poor, ambiguous or ill-matched system feedback	<b>X4</b>
No clear, direct and timely confirmation of an intended action from the portion of the system over which control is exerted	<b>X4</b>
Operator inexperience	<b>X3</b>
An impoverished quality of information conveyed procedures and person-person interaction	<b>X3</b>
Little or no independent checking or testing of output	<b>X3</b>
A conflict between immediate and long term objectives	<b>X2.5</b>
No diversity of information input for veracity checks	<b>X2</b>
A mismatch between the educational achievement level of an individual and the requirements of the task	<b>X2</b>
An incentive to use other more dangerous procedures	<b>X2</b>
Little opportunity to exercise mind and body outside the immediate confines of the job	<b>X1.8</b>
Unreliable instrumentation	<b>X1.6</b>
A need for absolute judgements which are beyond the capabilities or experience of an operator	<b>X1.6</b>
Unclear allocation of function and responsibility	<b>X1.6</b>
No obvious way to keep track or progress during an activity	<b>X1.4</b>

Table 3.13. Example HEART output (Source: Kirwan, 1994).

Type of Task - F		Nominal Human Reliability – 0.003	
Error Producing conditions	Total HEART effect	Engineer's POA	Assessed effect
Inexperience	X3	0.4	$((3 - 1) \times 0.4) + 1 = 1.8$
Opp Technique	X6	1.0	$((6 - 1) \times 1.0) + 1 = 6.0$
Risk Misperception	X4	0.8	$((4 - 1) \times 0.8) + 1 = 3.4$
Conflict of objectives	X2.5	0.8	$((2.5 - 1) \times 0.8) + 1 = 2.2$
Low Morale	X1.2	0.6	$((1.2 - 1) \times 0.6) + 1 = 1.12$

The assessed nominal likelihood for failure in the task analysed above is 0.27 ( $0.003 \times 1.8 \times 6 \times 3.4 \times 2.2 \times 1.12 = 0.27$ ). According to Kirwan (1994) this represents a high predicted error probability and would warrant error reduction measures. In this instance, technique unlearning is the biggest contributory factor and so if error reduction were required, retraining or redesign could be offered. Table 3.14 contains the remedial measures offered for each EPC in this example.

Table 3.14. Remedial measures (Source: Kirwan 1994).

<b>Technique unlearning (x6)</b>	The greatest possible care should be exercised when a number of new techniques are being considered that all set out to achieve the same outcome. They should not involve that adoption of opposing philosophies
<b>Misperception of risk (x4)</b>	It must not be assumed that the perceived level of risk, on the part of the user, is the same as the actual level. If necessary, a check should be made to ascertain where any mismatch might exist, and what its extent is
<b>Objectives conflict (x2.5)</b>	Objectives should be tested by management for mutual compatibility, and where potential conflicts are identified, these should either be resolved, so as to make them harmonious, or made prominent so that a comprehensive management-control programme can be created to reconcile such conflicts, as they arise, in a rational fashion
<b>Inexperience (x3)</b>	Personnel criteria should contain experience parameters specified in a way relevant to the task. Chances must not be taken for the sake of expediency
<b>Low morale (x1.2)</b>	Apart from the more obvious ways of attempting to secure high morale – by way of financial rewards, for example – other methods, involving participation, trust and mutual respect, often hold out at least as much promise. Building up morale is a painstaking process, which involves a little luck and great sensitivity

## Cognitive Simulation Techniques

More recently, cognitive simulations of human performance have been used in the prediction and analysis of human error. Such techniques are typically computerised simulations that attempt to replicate human performance in particular scenarios. These simulations can be used to generate the types of errors that human operators may make. Examples of cognitive simulation approaches include COSIMO (Cacciabue, Decortis, Drozdowicz, Masson, & Nordvik 1992), CAMEO-TAT (Fujita, Sakuda & Yanagisawa, 1994), SYBORG (Sasou, Takano & Yoshimura, 1996) and the Man-machine Integration Design and Analysis System MIDAS (Corker & Smith, 1993). Using cognitive simulations to predict human error is a useful concept in that it removes the dependency for sensitive error prediction from human analysts, and is also much quicker than the lengthy processes involved when using taxonomic or error identifier techniques. However, there is very little literature available regarding the sensitivity, reliability and validity of cognitive simulation to predict error, and such approaches are also expensive to apply.

## Summary

The advantages of HEI techniques are obvious. If the appropriate techniques are applied correctly they can be used to identify potential errors before they occur, allowing pro-active remedial measures to be taken. HEI techniques are relatively simple to learn and apply and produce extremely powerful data. However, HEI techniques are beset by a number of problems regarding the validity and sensitivity of the error predictions made. The validity of HEI techniques requires testing to ensure that their error predictions are accurate, while the reliability requires testing to ensure that the techniques offer the same error predictions when used by different analysts for the same task and when used more than once for the same tasks. HEI techniques depend heavily on the judgement of the analyst. Different analysts with different experience may make different predictions regarding the same problem (called inter-analyst reliability). Similarly, the same analyst may make different judgements on different occasions (intra-analyst reliability). Very few studies have been conducted to evaluate the reliability and validity of HEI techniques. A number of validation studies are reported in the literature (e.g. Whalley & Kirwan, 1989; Kirwan, 1992a, 1992b, 1997a, 1997b, 1998a, 1998b; Kennedy, 1995; Baber & Stanton, 1996, 2002; Salmon et al, 2002, 2003; Stanton & Stevenage, 1998). However, considering the number of HEI techniques available and their importance, this represents only a limited set of validation studies. Problems such as cost, time spent and access to systems under analysis often inhibit attempts to validate HEI techniques.

In terms of the sensitivity of the error predictions made, the literature indicates that the SHERPA approach is the most promising of the various HEI techniques available. For example, a number of validation studies have highlighted the SHERPA approach's superiority over other HEI approaches. For example, Kirwan (1992b) conducted a comparative study of six HEI techniques and reported that SHERPA achieved the highest overall rankings in terms of performance and ranking. In conclusion, Kirwan (1992b) recommended that a combination of expert judgement together with SHERPA would be the best approach to HEI. Additionally, studies concerning the prediction of errors arising from the use of public technology such as rail ticket machines and vending machines have also produced encouraging reliability and validity data for SHERPA (Baber & Stanton 1996, 2002; Stanton & Stevenage, 1998). In a recent comparative study of HEI approaches, Kirwan (1998b) used fourteen criteria to evaluate 38 HEI techniques. It was reported



that, of the 38 techniques, only nine are available in the public domain and are of practical use (Kirwan, 1998b), one being the SHERPA approach. The literature also indicates that the SHERPA approach offers the most potential for application within the road transport domain. This is based on the fact that the SHERPA approach has been applied successfully in a number of domains other than nuclear reprocessing (for which it was developed). For example, SHERPA has been used to predict potential errors arising from interaction with in-car technology (Stanton & Young, 1999), design induced error on civil flight decks (Salmon et al, 2002, 2003; Harris et al, 2005), and errors arising from the operation of rail ticket and vending machines.

### **3.2.4 Training**

Training is also used for error management purposes in complex, dynamic domains. Traditionally, retraining operators was the most common response to continued error occurrence in complex, sociotechnical systems, and novel training interventions and retraining were used to reduce error occurrence and the fallibility of human operator behaviour. Such interventions were based on the notion that specific training could reduce the variability in human behaviour, which in turn would lead to a reduction in the errors made by operators. Typically, error reduction-related training programs were reactive and focussed on developing operator skills to a point where errors would no longer be made. However, the continued tendency of highly skilled, experienced and well-trained operators to make even the most basic errors and the subsequent acceptance of the inevitability of error in complex, dynamic systems has led to the development of a new form of error-related training.

Error management training is a form of crew resource management (CRM) training used in civil aviation that attempts to provide flight crews with the skills required to detect and manage errors when they arise. Originally developed and applied within the aviation domain, CRM training is used to enhance the collaboration between, and performance of, flight crew members. CRM training programs were originally developed in response to analyses of aviation accident data which indicated that a high proportion involved pilot error (Helmreich, 2003). CRM is formally defined as “using all available resources – information, equipment and people – to achieve safe and efficient flight operations” (Lauber, 1984). Salas, Prince, Bowers, Stout, Oser, & Cannon-Bowers (1999) define CRM as “a set of teamwork competencies that allow the crew to cope with the situational demands that would overwhelm any individual crew member”.

CRM comprises a series of training methods that are used to introduce and develop specific competencies regarding effective collaboration and performance. Inherent within CRM programs is a focus upon enhancing the skills required for collaborative activity or ‘teamwork’ to improve performance. Original programs (known as cockpit resource management) had an emphasis on general behavioural strategies designed to enhance teamwork. The concept has since evolved considerably, and the latest CRM training programs (also known as error management training) emphasise the management of threat and error within the cockpit. Error management training is based upon the assumption that human actors are fallible and error is an inevitable feature of cockpit performance, and involves the use of strategies designed to highlight the limits associated with human performance and to aid the management of errors as they arise (Helmreich, Wilhelm, Klinect, & Merritt, 2001). CRM error management training programs aim to provide the following defences against errors:

1. Avoiding the error by preparation, planning and briefings;

2. Trapping the error by checking, inquiry, advocacy and vigilance; and
3. Mitigating the consequences of the error by developing decision-making strategies, task prioritisation and checklist management.

According to Helmreich (2003), contemporary CRM error management training programs comprise training issues regarding human limitations as sources of error, the nature of error and error management, expert decision making, conflict resolution, the use of specific strategies as threat and error countermeasures, formal review of relevant accidents and incidents, and practice in employing error countermeasures (e.g. simulation) with reinforcement for threat and error management. Helmreich (2003) also points out that effective CRM training programs are data driven and use information from a variety of sources, including surveys, observational study, and from the detailed analysis of errors, accidents and incidents. Using data derived from observational study of flights and also the analysis of the causal factors involved in a number of aviation accidents and incidents, researchers at the University of Texas developed a conceptual model of threat and error management (Helmreich, 2003). The model highlights the role of latent, internal and external threats in aircrew error, and demonstrates how error management strategies can be used to manage and mitigate errors as they arise. According to Helmreich (2003) organisations use the model as a guide for accident analysis and also for assessing the effectiveness of error management strategies. The model is presented in Figure 3.13.

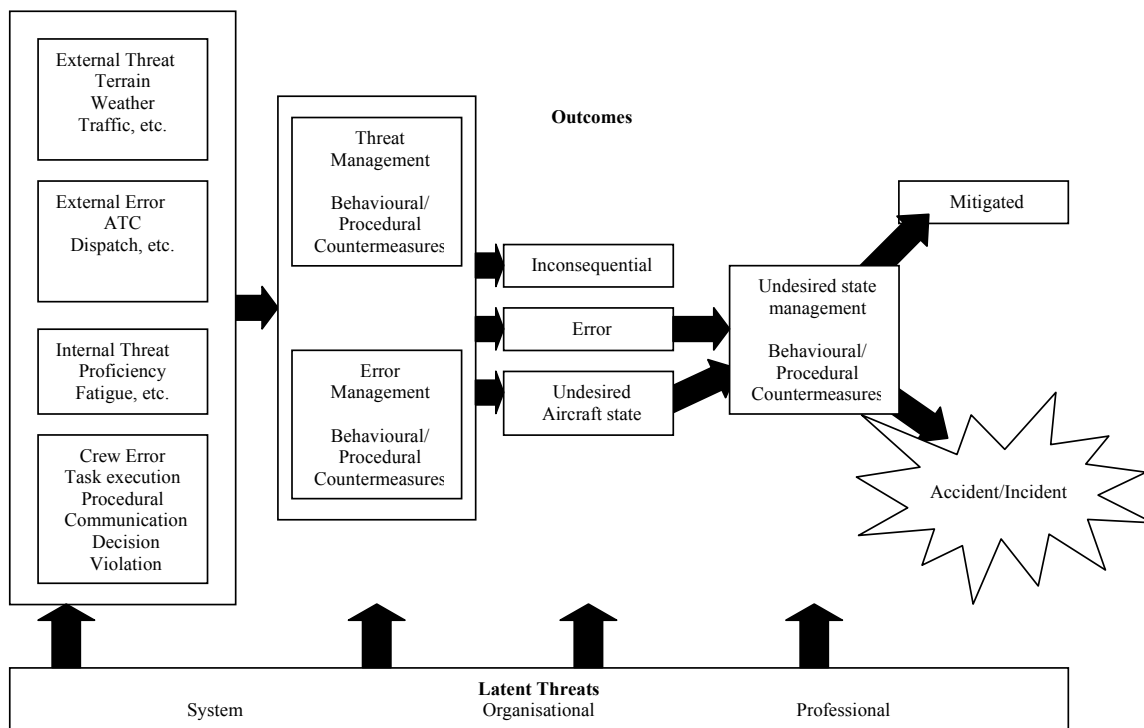


Figure 3.13. Threat and Error Management Model (Source: Helmreich, 2003).

Despite being developed within the civil aviation domain, CRM training programs have since been successfully applied in a number of different domains including offshore oil (O'Connor &

Flin, 2003), medicine (Howard, Gaba, Fish, Yang & Sarnquist, 1992), helicopter mountain rescue (Schmeiser, Bömmel & Bühren, 2000), air traffic control (Smith-Jentsch et al, 2001), maritime operations (Bydorf, 1998, Barnett, Garfield & Peckcan, 2004), nuclear power (Harrington & Kello, 1992; cited in Flin & O'Connor, 2001) and rail safety. According to Helmreich, Wiener & Kanki (1993) there is no theoretical reason why CRM training cannot be applied in domains other than aviation. Therefore it is feasible that CRM error management training could be used in other domains such as road transport. In a recent study conducted by MUARC, the potential for integrating CRM training principles into young driver training programs in the Australian Capital Territory (ACT) to enhance the positive, and minimise the negative, effects of passengers on young driver behaviour was investigated (Mitsopoulos, Regan, Anderson, Salmon & Edquist, 2005).

The study involved a literature review, an analysis of the differences between the driving and aviation domains, an analysis of the team-based activity and the knowledge, skills and attitudes required during driving to perform these activities, consultation with CRM experts from the aviation and medicine domains and the conduct of six focus groups involving young learner drivers, provisional licence drivers and course teachers. In conclusion to the study Mitsopoulos et al (2005) reported that the application of CRM training within young driver training programs is a viable concept and that the provision of CRM training could potentially enhance the positive effects of passengers on young driver behaviour. It is reasonable to conclude that error management training could be used as part of an error management program within the road transport domain. This would involve training road users in the skills necessary to detect and manage errors as and when they arise. Helmreich, Merritt & Wilhelm (1999) suggest that for such error management programs to gain acceptance, organisations must communicate their understanding that errors will occur and adopt a non-punitive approach to error occurrence (apart from wilful violations). Additionally, Helmreich et al (1999) also point out that organisations should strive to identify the nature and sources of error in their operations (e.g. through the use of incident reporting systems).

### **3.2.5 Error Databases**

Error databases form a critical component of error management in complex, sociotechnical systems. The culmination of error data collection efforts is typically a database containing descriptions of the different errors that have occurred within a particular system. A database containing the different errors that have occurred within a particular system, along with their associated causal factors and consequences, can be an extremely powerful resource. Error databases can be used for a number of purposes including in-depth studies, the identification of different error trends, the development of domain-specific taxonomies of error, quantitative error analysis, and to inform the development of error countermeasures. Most safety-critical systems have an error database of some form. For example, the Computerised Operator Reliability and Error Database (CORE-DATA; Basra & Kirwan, 1998) is a database of human or operator errors that have occurred within the nuclear, chemical and offshore oil domains. CORE-DATA contains over four hundred records describing errors and their associated causes, error mechanisms and probability of occurrence. CORE-DATA uses the following data sources as its input:

- incident and accident report data;
- simulator data from training and experimental simulations;

- experimental data;
- expert judgement data; and
- synthetic data.

The information within the CORE-DATA database is then analysed and classified based on the following key areas (Basra & Kirwan, 1998).

1. Task description: provides a general description of the task being performed and the operating conditions.
2. External Error Mode(s): provides a description of the observable manifestation of the error e.g. action too early, right action on wrong object, incorrect sequence etc.
3. Psychological Error Mechanisms: provides a description of the actor's internal failure modes e.g. attention failure, cognitive overload, misdiagnosis etc.
4. Performance Shaping Factors: provides a description of any performance shaping factors that contributed to the error e.g. ergonomic design, lack of supervision, task complexity etc.
5. Error opportunities: quantifies how many times the task was completed and the number of times the actor failed to achieve the desired outcome e.g. 1 failure in 50.
6. Nominal HEP: refers to the mean human error probability of a given task (HEP = number of errors observed divided by the number of opportunities for error).
7. Upper bound: the 95<sup>th</sup> percentile.
8. Lower bound: the 5<sup>th</sup> percentile.
9. Data Pedigree: refers to the type of data category e.g. simulator, expert judgement, real data.
10. Industry: refers to the domain from which the data came from (e.g. nuclear, petro-chemical, offshore etc).
11. Task/equipment: refers to the equipment and tasks involved in the incident.
12. Human action: refers to the cognitive process employed by the actor prior to the incident occurring.

To classify the error data, CORE-DATA uses the following sub-taxonomies:

- external Error Modes;
- psychological Error Mechanisms;
- performance shaping factors;
- task equipment; and
- task actions.

According to Basra & Kirwan (1998) potential uses for the data in the CORE-DATA database include error assessments, calibration data for HRA techniques, validation data for HRA techniques and guidance for assessors and regulators.

### 3.2.6 Traditional data collection techniques

In addition to the error management and data collection techniques described above, there are a number of traditional approaches that can be used to gather error-related data, including observational study, interviews, and questionnaires. Such techniques have been employed in the past for the collection of error data in a number of different domains, such as road transport (Reason, Manstead, Stradd, Baxter and Campbell, 1990) and civil aviation (Demagalski, Harris, Salmon, Stanton, Marshall, Waldmann & Dekker, 2002). The three main types of data collection technique used are observational study, interviews, and questionnaires. A brief description of each approach is given below.

#### Observational study

Observational study offers a simple and effective means of collecting human error data. There are many different forms of observation that can be classified under the following three broad categories: direct, indirect and participant observation. Observation has been used in the past to collect error information in a number of domains, including public technology use (Baber & Stanton, 1996; Stanton & Stevenage, 1998), road transport (Wierwille, et al, 2002) and many more. For example, Wierwille et al (2002) used site surveillance at 31 roadway sites in order to collect critical incident data (a critical incident being a traffic event in which a conflict occurred between two or more vehicles or between a vehicle and a pedestrian). The critical incident method (or traffic events method) was used to determine the types of errors that drivers make and to assess the associated contributing factors. Data collection involved the use of five techniques, including videotape surveillance of the site, experimenter annotations (field notes), in-vehicle drive through video, site inventory and photography. Over 200 hours of video recordings were made and over 1,200 critical incidents were captured and analysed (Wierwille et al, 2002). Amongst other things, Wierwille et al (2002) reported that, in 57% of the critical incidents analysed, 'wilful inappropriate behaviour' was identified as the principal contributor, while 'inadequate knowledge' and 'infrastructure' were identified as the principal contributors in 23% and 20% of the incidents respectively.

In-car video recordings can also be used to collect error-related data. So called naturalistic driving studies involve the use of in-vehicle recording devices. For example, DriveCams driving behaviour management system (<http://www.drivecam.com>) uses video recording devices to record driver activity and also the driving scene. Recorded events are then analysed using the hindsight 2020 software, and feedback is developed and provided based on the analysis. The DriveCam system provides an example of how human error-related data could potentially be derived from in-vehicle recording systems. Such data could potentially be used to derive information regarding the nature and consequences of driver errors. For example, the recent Virginia Tech Transportation Institute 100-Car Naturalistic Driving Study (Klauer, Neale, Dingus, Ramsey, & Sudweeks, 2005) involved the use of 100 instrumented cars to continuously collect naturalistic driving data over a 12 month period. The data collected included data on 69 crashes, 761 near crashes, and 8295 incidents (Klauer et al, 2005). The data has been used to date to, amongst other things, analyse driver inattention and distraction (Klauer et al, 2005) and also driving performance in familiar and unfamiliar vehicles.

Despite the advantages of using observational study to collect error data, such as its simplicity and the empirical nature of the data collected, the use of observation to collect error information is

fraught with problems. The main concern surrounds the quality of the data collected. While the data is empirical and many error-related crashes and near misses may be recorded, it may be very difficult to derive specific information regarding the nature and causes of any driver errors recorded. For example, we may be able to derive from such data that the rear impact crash was driver A's fault for not braking early enough on approach to an intersection. However, why the driver did not brake early enough cannot be reliably assumed from visual data only. The primary driver error in this case may have been a slip (driver pressed the accelerator instead of the brake as was planned), a lapse (driver forgot to press the brake), a mistake (driver intended not to slow down until he did) or a violation (driver felt that by not slowing down, he or she could pass through a gap in the traffic). Without actually speaking to the driver involved we cannot accurately determine why the error was made and what sort of error it was (e.g. slip, lapse, mistake or violation) from observational data alone.

Additionally, the use of observation to collect error data does not permit the identification of certain latent conditions and preconditions for unsafe acts. While environmental and road infrastructure-related information may be derived from such data, various factors, such as driver and vehicle-related factors cannot. Taking the example above, observational data would not tell analysts that the driver involved was fatigued, was desperate to get home, and that the vehicle brakes were sub-standard. Additionally, such data do not reveal anything regarding the cognitive components of the errors observed. Thus it is impossible to exhaustively identify the contributory factors and latent conditions involved in the error-related accidents and incidents recorded. One way around this is to interview the road users involved in the accidents and incidents recorded. However, this would require considerable financial and human resources.

Another problem is the intrusive nature of observational techniques. It is widely reported that people modify their behaviour if they know they are being observed. In complex, sociotechnical systems operators may behave in total compliance with procedures while under observation in the fear that there will be reprisals should they ignore rules and procedures. This is particularly problematic when studying error as operators may take extra care in their performance if they are being observed, and typical errors may not arise. One way to resolve this problem is to use covert observation, where the participants do not know they are being observed. It is, however, often difficult to gain ethical clearance for such studies. Observational studies are also lengthy and the analyst has a distinct lack of experimental control. For instance, it is possible that no errors occur during an observation period. Finally, observational study data are extremely time consuming and laborious to analyse.

## **Interviews**

Interviews can also be used to gather error data from participants. There are three types of interview available: structured, semi-structured and unstructured. Interviews offer a very flexible means of gathering large amounts of error data and are relatively simple to conduct. Researchers have complete control over the structure of an interview, and can guide it in any direction that they see fit. Participants can also be questioned in order to gain a deeper insight into factors surrounding errors, such as contributory factors and recovery measures. Interviews could be used in conjunction with observational study to determine the factors surrounding error occurrence. Despite their appealing nature, interviews also have a number of disadvantages. These include difficult and time consuming design, and the lengthy and laborious process involved in the coding and analysis of interview data. Additionally, interviews are prone to a number of interviewer and

interviewee biases. For example, participants may not wish to reveal errors that they have made during an interview for fear of reprisals.

## Questionnaires

Questionnaires can also be used to gather pertinent error data. Like interviews, questionnaires offer a flexible means of gathering large amounts of data. Questionnaires also have the added benefit of being administered easily to large populations. In a recent study investigating design induced pilot error on civil flight decks, Marshall et al (2003) used a questionnaire to identify error incidence for the flight task 'Land aircraft X at New Orleans airport using the autoland system'. The questionnaire was based upon a HTA and SHERPA error analysis of the flight task. Respondents were asked if they had ever made the error themselves, and also if they knew of any other pilots who had made the error. The questionnaire was administered to 500 UK airline pilots and 46 were returned. A total of 57 errors were reported by questionnaire respondents for the flight task in question. Reason, Manstead, Stradd, Baxter and Campbell (1990) also developed and used the Driver Behaviour Questionnaire (DBQ) to collect error data from drivers in the road transport domain. The DBQ has since been extensively used to collect driver error data in a number of different studies. Questionnaires are advantageous in that they can be administered easily and with minimum cost and resources to a very large population sample (e.g. by post) and can be used to gather a large amount of data remotely. However, the typical response rate to postal questionnaires is only 10% and often the data received contains non-committal responses. Further, questionnaire data are prone to a number of biases, and are also time consuming to collate and analyse.

Traditional data collection techniques, such as observational study, interviews and questionnaires offer a simple means for collecting error-related data. Such approaches are typically inexpensive and can be used to collect large volumes of error data. All three of the techniques described above have been used in road transport and other domains in the collection of human error-related data. For example, Wierwille et al (2002) used site surveillance to collect critical incident data and Reason, et al (1990) developed the DBQ to collect error data from drivers. Despite their simplicity and the low cost incurred, a number of disadvantages may affect the data that is collected using such approaches, such as biases, time consuming data analysis and low response rates. However, despite these disadvantages, it is apparent that these approaches are particularly suited to the collection of error-related data within the road transport domain.

## 3.3 Examples of Contemporary Error Management Approaches

In the previous section, an overview of the component techniques that are used as part of error management programs in domains other than road transport was presented. A combination of these techniques is typically used to form error management programs within complex, dynamic domains. In addition to these techniques, a number of approaches have also been developed specifically for error management purposes. In the following section, an overview of specific error management techniques from the aviation, oil exploration and production, and rail transport domains is presented.

## Aviation

Error management programs are prominent in the aviation domain. According to Helmreich (2003) three factors have contributed to the management of error within the aviation domain. These are the introduction of CRM training programs, which address the interpersonal aspects of flight operations, the collection and analysis of data, which attempts to provide an accurate picture of the strengths and weaknesses of organisations and the aviation system, and the development of safety cultures that cope with sources of threat and error. One example of an error management program currently employed within the aviation domain is Boeing's Safety Management System (BSMS) program. The Boeing Safety Management System comprises four incident investigation tools: the Procedural Event Analysis Tool (PEAT); the Maintenance Error Decision Aid (MEDA) technique; the Cabin Procedural Investigation Tool (CPIT); and the Ramp Error Decision Aid (REDA) technique. The aim of the BSMS is that the tools are used to investigate incidents and inform the development of countermeasures designed to prevent the future occurrence of similar incidents. The BSMS process is presented in Figure 3.14.

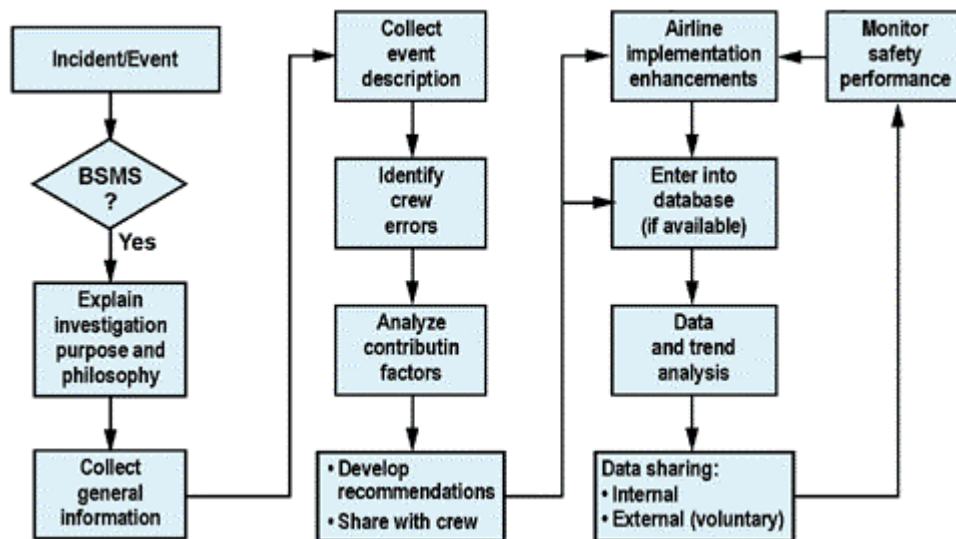


Figure 3.14. BSMS process.

According to the Boeing website, the BSMS tools are designed to significantly improve accident and incident investigations and focus on the cognitive aspects surrounding the incident under analysis to identify not who was responsible, but how and why incidents were allowed to occur. This represents an attempt to move away from the person approach to human error towards the systems approach. According to the Boeing website, the BSMS offers the following benefits:

- structured, systematic approach to investigations;
- consistent application and results;
- visibility of incident trends and risk areas;



- reduction or elimination of procedural-related events;
- improved operational safety;
- improved economic efficiencies;
- a means for communicating and sharing relevant information between organisations, both internal and external to the airline; and
- compatibility with existing industry safety tools.

A brief description of the BSMS tools is provided in the following section.

### Procedural Event Analysis Tool (PEAT)

Within the aviation domain, the rigorous analysis of accident and incident data is seen as the most effective way to make progress in safety improvements (Graeber & Moodi, 1998). From a review of 10 years of commercial jet aircraft accidents (1982 –1991) conducted by Boeing, a series of accident prevention strategies that could have prevented each accident were identified. Further, pilot adherence to established procedures was identified as the strategy that could have prevented the greatest number of accidents (almost 50%) during the 10 years. The Procedural Event Analysis Tool (PEAT; Graeber & Moodi, 1998) was developed in response to these findings, and is a software-based accident and incident analysis technique that is used to identify the underlying cognitive factors that contribute to procedural deviations. PEAT was designed to be used during accident and incident investigations and to aid the development of countermeasures designed to address or eliminate the contributory factors associated with incidents involving procedural deviation. The PEAT procedure comprises three key phases: a process; data storage; and analysis (Graeber & Moodi, 1998). The PEAT procedure is presented in Figure 3.15.

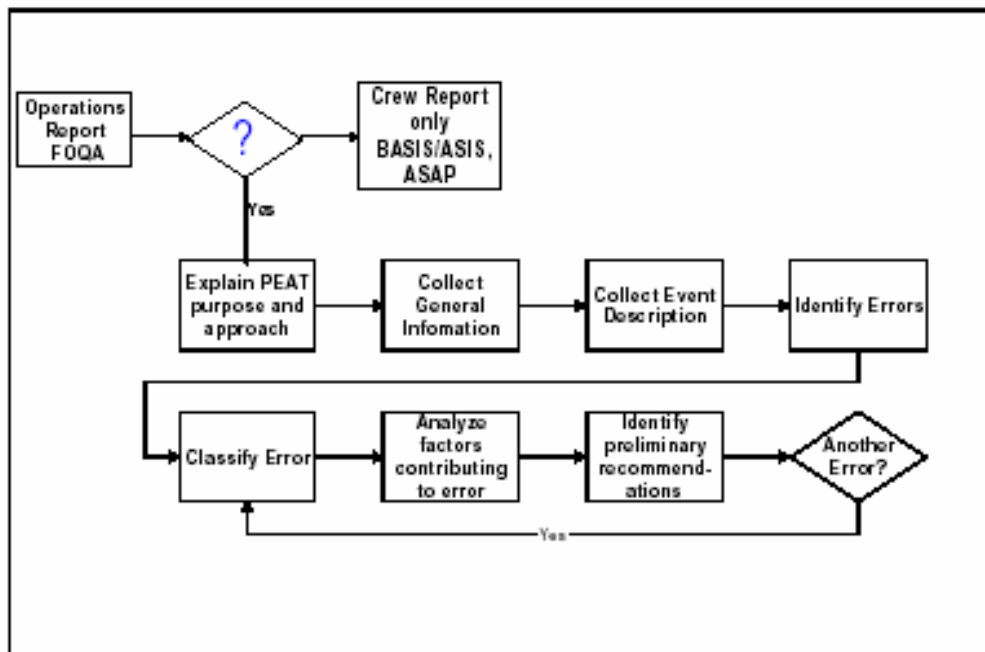


Figure 3.15. PEAT procedure (Source: Graeber & Moodi, 1998).

The PEAT technique considers the following 7 categories of contributing factors:

- procedural;
- equipment;
- situational awareness;
- performance shaping;
- crew co-ordination/communication;
- environmental/facility; and
- technical knowledge/skills/experience.

PEAT is used to establish both the contributory causes and also the effects of the incident under analysis. A typical PEAT analysis involves conducting structured interviews with the flight crew members involved in the incident under analysis. Initially, the crew member in question is asked for recommendations that might prevent similar incidents occurring in the future. The analyst then uses the PEAT interview form to determine what actions led to the event, and what contributory factors were involved in facilitating the incident. Moodi & Kimball (2004) present an example PEAT analysis of an incident that involved an aircraft overrunning a runway on landing. An extract of a PEAT analysis (Source: Moodi & Kimball, 2004) is presented in Table 3.15.

Table 3.15. PEAT analysis extract (Source: Moodi & Kimball, 2004).

Deviation	Fuel Dispatch Process	Fuel/Time Pressure	WX Reports	Alternate WX	Over-confidence	CRM	Control Layout	Complacency due to equipment reliability
#1. PF did not request additional fuel prior to departure.	X		X					
#2. PF did not initiate a diversion when fuel quantity reached divert level.		X		X	X			
#3. PF did not arm spoilers.		X					X	
#4. PNF did not challenge PF for request for clearance amendment.		X			X	X		
#5. PNF did not verify spoiler arming.		X					X	
#6. PF did not go-around.		X		X	X			
#7. PNF did not manually deploy the spoilers.								X

## Maintenance Error Decision Aid (MEDA)

Reason (1997) describes the Maintenance Error Decision Aid (MEDA) approach, which is an aviation maintenance error investigation technique developed by Boeing in collaboration with the FAA and Galaxy Scientific Corporation. The MEDA approach is an accident and incident investigation tool used to identify the contributory factors involved in maintenance error incidents and to aid the development of countermeasures designed to reduce maintenance error occurrence. The MEDA approach uses two levels of investigation: line investigation and organisational trend analysis. According to Reason (1997) the MEDA approach comprises five phases. Phases one to three are concerned with what happened during the incident under analysis, phase 4 is concerned with addressing how and why the incident occurred, and phase 5 is used to pinpoint failed defences within the system and also propose remedial measures or solutions. A brief description of each phase is presented below (adapted from Reason, 1997):

1. Phase 1. Used to gather general information regarding the incident under analysis, including the airline and aircraft involved, and the time of the incident etc.
2. Phase 2. Used to describe the nature of the incident under analysis e.g. flight delay, in-flight shutdown etc.
3. Phase 3. Involves classifying the nature of the errors involved in the incident under analysis. The following categories are used: improper installation; improper servicing; improper or incomplete repair; improper fault isolation; inspection or testing; foreign object damage; surrounding equipment damage; and personal injury;
4. Phase 4. Involves identifying the factors that contributed to the incident under analysis. MEDA provides the analyst with a contributing factors checklist. This checklist is then completed for each of the errors identified during phase 3. The contributing factors include: information; equipment; tools or parts; aircraft design and configuration; job or task; qualifications and skills; individual performance; environment and facilities; organisational environment; supervision and communication; and
5. Phase 5. Comprises two stages (5a & 5b). 5a involves determining whether or not there were any procedures, processes and policies already in existence that should have prevented the incident from occurring in the first place, whereas phase 5b is used to identify the corrective measures that should be taken to prevent the recurrence of the incident.

According to Boeing, benefits from MEDA implementations include revised and improved maintenance and airline work procedures, reductions in aircraft damage through improved towing procedures, improved in line maintenance workload planning and a reduction in on-the-job accidents and incidents.

## Cabin Procedural Investigation Tool (CPIT)

The CPIT tool is used to determine the contributory factors and effects associated with cabin crew procedural deviation incidents. The CPIT procedure uses 4 main categories of contributing factors: procedural/training; equipment/work area; individual/performance shaping; and crew co-ordination/communication factors. The CPIT uses general event information and information derived from structured interviews with the cabin crew involved in the incident as its main input. The CPIT procedure involves asking the crewmember(s) involved for recommendations that

would prevent a similar incident occurring, determining the actions that led to the incident, determining the contributing factors that influenced the decisions and actions that led to the incident, and developing recommendations aimed at reducing or eliminating the effects of the contributory factors identified. The CPIT is different from other retrospective incident analysis techniques in that the crew member who was actually involved in the incident identifies the contributory factors, rather than the analyst. An extract of a CPIT analysis is presented in Figure 3.16 (Source: Moodi & Kimball, 2004).

<p><b>Procedural Error #1:</b> CA#1 opened main door without disarming slide.  <b>Reference # 03-737-22</b></p>
<p>Related specific procedure steps or tasks and source:</p> <ol style="list-style-type: none"> <li>1. Ensure door area is clear and jet way is in place.</li> <li>2. Remove red flag from window.</li> <li>3. Disarm door (move girt bar) and open door.</li> </ol>
<p>Section V:</p>
<p><b>A. Contributing factors</b> (include CPIT classification code):</p> <p>CF#4: Cabin attendant was rushed to open the door by the passenger service agent. Code: <b>C6</b></p> <p>CF#5: Cabin attendant #1 (CA#1) thought Cabin attendant #2 (CA#2) had disarmed the main door. Code: <b>C4</b></p>
<p><b>B. Rational for contributing factor(s):</b></p> <p>CF#4: The passenger service agent knocked on the door to expedite manifest transfer. This is normally done when the door is disarmed, unlocked, but still closed. So this was a miscue to the cabin attendant (CA#1).</p> <p>CF#5: The other cabin attendant (CA#2) moved to the main door to assist CA#1. CA#2 was in the process of disarming the door, but had not fully completed the procedure due to distraction. Her warning to CA#1 about the door status came too late as CA#1 was trying to help an on-time departure.</p>
<p>Section VI:</p>
<p><b>A. General Recommendation(s):</b></p> <p>CF#4: Cabin attendants should not feel rushed by passenger service staff. This is a team effort.</p> <p>CF#5: Cabin attendants should apply cross checking procedures whenever they can.</p>
<p><b>B. Specific Recommendation(s):</b></p> <p>CF#4: The factors of this event will be discussed briefly in annual recurrent training. Cabin attendants will be reminded they are team players with passenger service staff, but not under their authority.</p> <p>CF#5: The following cross check procedure should be considered by the standardization and training departments: During non-routine door openings and when two cabin attendants are present, a verbal verification of door arming status should be exchanged between the attendants.</p>

Figure 3.16. CPIT analysis extract (Source: Moodi & Kimball, 2004).

## Ramp Error Decision Aid (REDA)

It is estimated that ramp accidents (i.e. accidents that occur on the ground around the airport perimeter) cost the airline industry up to \$2 million annually, and that a high proportion of these incidents are caused, in part at least, by human error. The REDA approach is an incident investigation tool that was developed by Boeing to identify the contributory factors involved in maintenance and other ground operation personnel (e.g. baggage handlers) incidents involving human error. The REDA approach is based upon the MEDA approach described above, and is also used to develop countermeasures designed to reduce maintenance and ground service incidents caused by human error. REDA is used to identify the physical, organisational and cognitive factors that have a negative affect on worker and system performance (Rankin & Sogg, 2004). The REDA approach uses the following 10 categories of contributing factors:

- information;
- equipment/Tools/Safety Equipment;
- aircraft Design/Configuration/Parts;
- job/Tasks;
- technical Knowledge/Skills;
- individual factors;
- environment/Facilities;
- organisational Factors;
- leadership/Supervision;
- communications; and
- other.

The REDA procedure involves retrospectively analysing incidents through the use of structured interviews with the ramp workers involved in the incident. The interview is used to identify the following:

- the factors that contributed to the system failure in question; and
- ideas that the ramp worker involved has for eradicating/improving or fixing the contributing factors identified.

Rankin & Sogg (2004) present a REDA analysis of an incident that involved the left engine nacelle (engine housing) of a Boeing 737-400 striking a service truck while being guided into the gate. An extract of the REDA analysis is presented in Figure 3.17 (Source: Rankin & Sogg, 2004).

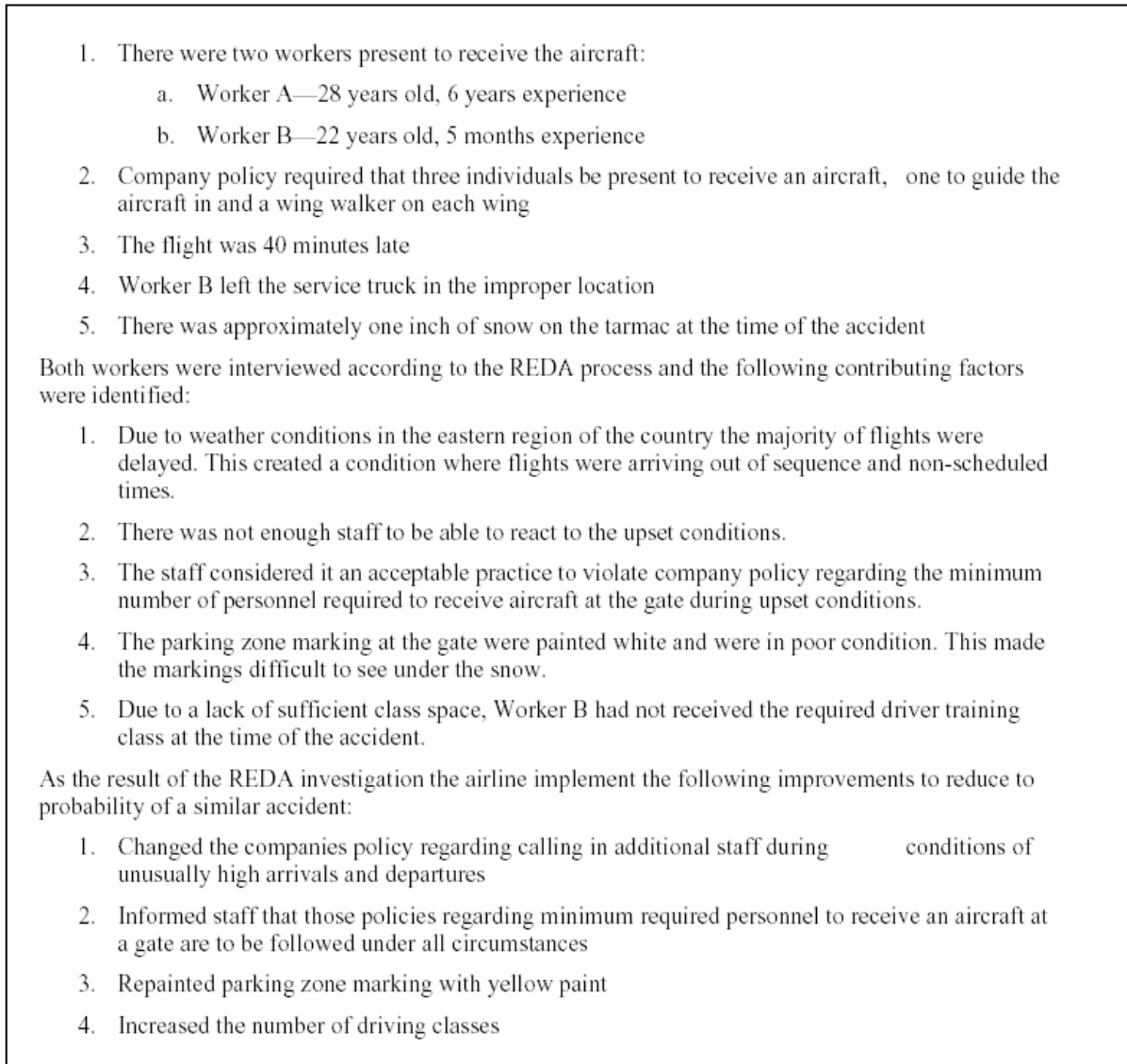


Figure 3.17. REDA analysis extract (Source: Rankin & Sogg, 2004).

The output of REDA analyses are typically used to develop countermeasures designed to address or remove the contributory factors highlighted in the analysis.

## Oil Exploration and Production

### TRIPOD-DELTA

The TRIPOD-DELTA approach was developed for the oil exploration and production domain by researchers from the Universities of Manchester and Leiden (Reason, 1997). According to Reason (1997) TRIPOD-DELTA has a tripartite structure (see Figure 3.18) and its underlying philosophy centres around the measurement, control and minimisation of general failure types (GFTs) which are defined as those processes that disrupt safe operations.

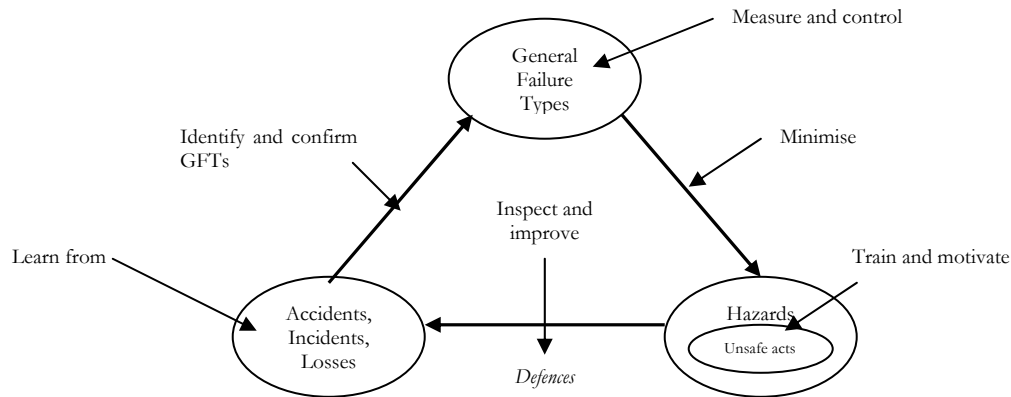


Figure 3.18. Tripod Delta structure (adapted from Reason, 1997).

The TRIPOD-DELTA approach considers the following broad categories of GFTs:

- hardware – the quality and availability of tools and equipment within the system in question;
- design – inadequate design that leads directly to errors and violations;
- maintenance management – the management of maintenance activities within the system in question;
- procedures – the quality, accuracy, relevance, availability and workability of system procedures;
- error enforcing conditions – refer to those conditions that lead to unsafe acts, including error producing conditions and violation promoting conditions;
- housekeeping – influenced by personnel, poor incentives, poor hardware etc;
- incompatible goals – individual, group and organisational goal conflicts that lead to errors and violations;
- communications – communications-related problems, including either lack of adequate or appropriate communications technology, a failure for information to be communicated, misinterpreted communications or communications that occur too late;
- organisation – deficiencies within organisations that impact safety and allow errors and violations to occur;
- training – refers to various training problems, including misinterpretation of training requirements, obstruction of training and inadequate training assessment; and
- defences – failures in the various defences within a particular system, including detection, warning, recovery and containment (Reason, 1997).

TRIPOD-DELTA uses checklists containing indicators of the presence and degree of the GFTs listed above. Operators from the system in question (e.g. line managers) use the checklist to determine the presence of each GFT. Each GFT has an associated checklist consisting of 20 indicators selected by the computer program from a set of 200 indicators for each GFT.

Examples of indicators for the design GFT include, ‘was this platform originally designed to be unmanned?’, ‘are shutoff valves fitted at a height of more than two metres?’, and ‘is standard company coding used for the pipes?’ (Reason, 2005). Operators answer each of the indicators with a simple ‘yes’ or ‘no’ reply. Once the initial assessment is completed the TRIPOD-DELTA software generates for each GFT a failure state profile, which is a bar chart presenting a ‘cause for concern’ rating for each of the 11 GFTs. The cause for concern rating refers to the number of indicators out of the 20 that are scored in the concern direction. This allows for the identification of the GFTs within the system that are the most in need of attention. According to Reason (1997) the relevant line managers should then review the failure state profiles and develop appropriate remedial measures for the two or three worst GFTs.

## **Rail Transport**

### **REVIEW**

The success and utility of the TRIPOD DELTA approach led to the development of the REVIEW approach, which is based on the TRIPOD-DELTA method and was developed by the University of Manchester for use in the rail transport domain. REVIEW evaluates the following 16 railway problem factors (RPFs) that were generated as a result of extensive railway field studies (Reason, 1997):

- tools and equipment;
- materials;
- supervision;
- working environment;
- staff attitudes;
- housekeeping;
- contractors;
- design;
- staff communication;
- departmental communication;
- staffing and rostering;
- training;
- planning;
- rules;
- management; and
- maintenance.

Similar to TRIPOD DELTA, the REVIEW approach involves assessors (e.g. line managers or front line operators) answering indicators for each RPF based on the degree to which each of the RPFs have constituted a problem since the last REVIEW assessment. The results are summarised in bar charts which are used to identify those RPFs that are a particular cause for concern.



### 3.4 Summary

Error management programs are employed in most safety-critical domains. Typical error management programs use formal methods to gather and analyse error-related data which is then used to develop a thorough understanding of the nature of, and factors surrounding, error occurrence in a particular system. The main aims of such programs are the eradication, reduction, mitigation and management of errors and their consequences. The literature indicates that there are a number of different error management-related approaches available and that these techniques and programs have been implemented as part of error management programs in a wide range of domains. A summary of the error management related techniques, methods and approaches discussed is presented below:

- Accident investigation and analysis. Retrospective accident analysis and investigation involves the use of structured techniques to identify the human and system contributions to accidents. There are various accident analysis techniques available, such as HFACS, ICAMS, fault tree analysis, AcciMaps, and TRACEr. Accident analysis is attractive for a number of reasons: it exposes investigators to the entire sequence of events, including triggering conditions, and outcome; it permits the identification of the human and systemic causal factors involved in a particular accident and also the identification of system failures or latent conditions, such as bad design, inadequate training, inadequate equipment and poor management; and it aids the development of countermeasures designed to prevent similar accidents occurring in the future. Accident analysis approaches are, however, beset by a number of problems, including the apportioning of blame to individuals and the various problems associated with hindsight;
- Incident reporting systems. Incident reporting systems are used to collect pertinent information regarding critical incidents (or near misses), errors, safety compromising incidents and safety concerns within complex sociotechnical systems. Incident reporting systems are now common in most safety-critical domains, including aviation (e.g. ASRS), healthcare (e.g. MedWatch) and nuclear power (e.g. MARS). The utility of such systems lies in their ability to capture large amounts of incident or near miss data that would otherwise go un-noticed or unreported. Incident reporting systems work on the premise that near misses are indicators of accidents waiting to happen, and allow preventative measures to be taken before accidents occur. The data obtained are useful as they can be used to identify the types of errors made, their causes, and recovery strategies for a particular system. Despite the various advantages associated with the collection of near miss data and the use of incident reporting systems, there are a number of disadvantages that may affect the data collected. These include reluctance by system personnel to report such incidents for a number of reasons, perceived worthlessness and scepticism of such schemes, problems relating to the accuracy of incident descriptions, the high cost associated with running such schemes, and the various biases to which incident report data are subject;
- Human error identification. HEI techniques are used to predict potential human or operator error in complex, dynamic systems. There are a number of different HEI approaches available including taxonomy-based techniques, error identifier techniques, error quantification techniques, cognitive modeling techniques and cognitive simulation techniques. HEI techniques have previously been employed in a number of different domains, including the nuclear power and petro-chemical processing industry (Kirwan, 1999), air traffic control (Shorrock & Kirwan, 2000), aviation (Marshall et al, 2003), naval operations, military systems,

space operations (Nelson et al, 1998), medicine and public technology (Baber & Stanton, 1996). The utility of HEI techniques lies in their ability to identify potential errors before they occur, allowing pro-active remedial measures to be taken. This also allows them to be applied early in the design process, before an operational system exists. HEI techniques do, however, suffer from a number of problems, including issues regarding the reliability and validity of such techniques. For example, different analysts, with different experience, may make different error predictions for the same task (inter-analyst reliability). Similarly, the same analyst may make different judgements on different occasions (intra-analyst reliability);

- Training. Training is also typically used as a part of error management in complex, dynamic systems. Traditionally, retraining operators was the most common response to continued error occurrence in complex, dynamic domains, and novel training interventions and retraining were used to try and reduce error occurrence in such systems. Error management training is an example of a contemporary training approach to error management. Error management training is a form of crew resource management (CRM) training that attempts to provide operators with the skills (technical and non-technical) to detect and manage errors as they arise.
- Error databases. The culmination of error-related data collection in complex, dynamic domains is typically the development of an error database. Error databases are used for a number of purposes including in-depth studies, the identification of different error trends, quantitative error analysis and to inform the development of error countermeasures.
- Traditional data collection techniques. Established data collection approaches such as observational study, interviews and questionnaires are also used to collect human error-related data in complex, dynamic domains. Such approaches offer a simple way of collecting error-related data, are typically inexpensive and can be used to collect large volumes of error data;
- Specific error management techniques. A number of approaches have been developed specifically for error management purposes in safety-critical domains. Techniques such as TRIPOD DELTA, REVIEW and MESH are used to manage error within their respective domains. Such approaches work by identifying the extent to which latent conditions are a problem for concern, and then informing the development of countermeasures designed to reduce the latent conditions identified; and
- General error management techniques. Other, more general approaches to error management are also adopted within complex, sociotechnical systems. Procedures, checklists, system redesign, awareness campaigns and the introduction of novel technology and artifacts can all be used as error management strategies.

It was concluded that a number of key aspects of error management should be considered when designing and implementing error management programs. Briefly, the effectiveness of error management programs appears to be entirely dependent upon the collection and analysis of accurate data regarding the nature of, and contributory factors associated with, errors and latent failures within the system in question. The error data collected is key to identifying and understanding the errors and causal factors involved, and also to the development of strategies and countermeasures designed to manage, eradicate or tolerate error occurrence. A number of general conclusions regarding error management in safety-critical domains can be drawn from the literature review:

- error management programs have been implemented in a number of different domains, including civil aviation, medicine, nuclear power and rail domains;
- error management programs are used to understand better the nature of errors and latent conditions within systems, identify and develop countermeasures, procedures and behaviours that might lead to the mitigation of these errors and latent conditions, and promote error tolerance within systems;
- most error management programs adopt a systems, rather than a person approach to error within complex systems and consider the combined role of latent conditions and errors in accident causation;
- most error management programs are based on the acceptance that humans make errors, and focus on the development of error tolerance within systems rather than the eradication of error;
- there are numerous error management-related techniques available, including incident reporting systems (e.g. ASRS), accident investigation tools (e.g. HFACS), human error identification techniques (e.g. SHERPA), and error management training programs (e.g. CRM);
- error management programs normally employ a mixture of the error management-related techniques available, and the techniques used depend on the domain in which the program is implemented;
- error management programs depend on the collection of accurate data on the nature of, and contributory causes associated with, errors in complex, dynamic systems;
- the success or effectiveness of error management programs is difficult to measure or quantify;
- there have been only limited attempts to implement error management programs in the road transport domain worldwide; and
- to date there has been no attempt to embed human error management into risk management within road transport on an ongoing basis



# Chapter 4 Human Error and Road Transport

## 4.1 Introduction

In the preceding chapters, an overview of human error-related research in domains other than road transport and human error management-related techniques and approaches employed in those domains was presented. The next phase of our study involved reviewing the human error-related research that has been conducted to date in the road transport domain.

The results of the literature review indicate that in comparison to other domains in which human error has been identified as a major problem, the construct has received relatively little attention within road transport. This is surprising when the apparently significant role of human error in road traffic accidents is considered. For example, it has previously been estimated that human or driver error contributes to as much as 75% of all roadway crashes (Hankey, Wierwille, Cannell, Kieliszewski, Medina, Dingus & Cooper, 1999; cited in Medina, Lee, Wierwille & Hanowski, 2004). Additionally, it has also been estimated that human actions are involved in up to 95% of traffic crashes (Rumar, 1995; cited in Aberg & Rimmo, 1998). This chapter presents an overview of the human error-related research that has been conducted to date in road transport, and identifies and describes any road safety programs worldwide that recognise the contribution of human error in accident causation. This chapter comprises the following sections:

- results of the literature review of the human error-related research conducted to date within the road transport domain;
- discussion of the different approaches to human error and risk management in the road transport domain worldwide; and
- discussion of the current approach to human error and risk management in the road transport domain in Australia.

## 4.2 Review of Human Error-Related Research Conducted in the Road Transport Domain

The literature review indicates that, although limited in relation to the amount of human error-related research conducted in other complex, dynamic domains, there has been some human error-related research conducted in road transport. The following section presents an overview of this. Using the person and systems approach dichotomy described in the previous chapter, the human error-related research conducted in the road transport domain can be broadly categorised into person-related and systems-related research.

## 4.2.1 Person-Based Human Error Research

### Error classification

A number of studies were conducted in the late 1970s and early 1980s with the aim of identifying and classifying the types of errors that different driver groups make. Two of the more widely reported studies are described by Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansifer, & Castellan (1977; cited in Wierwille et al, 2002) and Sabey & Taylor (1980). Treat et al (1977; cited in Wierwille et al, 2002) describe a program of research that was conducted at the Indiana University for Research in Public Safety. The study investigated the classification of driver errors and contributory factors involved in road traffic accidents. Error data were collected from documented incident cases, on-site accident investigations, and accident evaluations (Wierwille et al, 2002). Four primary groups of incident causation factors were identified. These were human conditions and states (physical/physiological, mental/emotional, experience/exposure), human direct causes (recognition errors, decision errors, performance errors), environmental factors (highway related, ambient condition) and vehicular factors. The incident causation factors taxonomy is presented in Table 4.1.

Table 4.1. Driver error and incident causation factors (adapted from Wierwille et al, 2002).

1. Human conditions and states		
A. Physical/Physiological	B. Mental/Emotional	C. Experience/Exposure
<ul style="list-style-type: none"> <li>• Alcohol impairment</li> <li>• Other drug impairment</li> <li>• Reduced vision</li> <li>• Critical non-performance</li> </ul>	<ul style="list-style-type: none"> <li>• Emotionally upset</li> <li>• Pressure or strain</li> <li>• In hurry</li> </ul>	<ul style="list-style-type: none"> <li>• Driver experience</li> <li>• Vehicle unfamiliarity</li> <li>• Road over-familiarity</li> <li>• Road/area unfamiliarity</li> </ul>
2. Human direct causes		
A. Recognition errors	B. Decision errors	C. Performance errors
<ul style="list-style-type: none"> <li>• Failure to observe</li> <li>• Inattention</li> <li>• Internal distraction</li> <li>• External distraction</li> <li>• Improper lookout</li> <li>• Delay in recognition for other or unknown reasons</li> </ul>	<ul style="list-style-type: none"> <li>• Misjudgement</li> <li>• False assumption</li> <li>• Improper maneuver</li> <li>• Improper driving technique or practice</li> <li>• Inadequately defensive driving technique</li> <li>• Excessive speed</li> <li>• Tailgating</li> <li>• Excessive acceleration</li> <li>• Pedestrian ran into traffic</li> </ul>	<ul style="list-style-type: none"> <li>• Panic or freezing</li> <li>• Inadequate directional control</li> </ul>
3. Environmental factors		
A. Highway related	B. Ambient condition	
<ul style="list-style-type: none"> <li>• Control hindrance</li> <li>• Inadequate signs and signals</li> <li>• View obstruction</li> <li>• Design problems</li> <li>• Maintenance problems</li> </ul>	<ul style="list-style-type: none"> <li>• Slick roads</li> <li>• Special/transient hazards</li> <li>• Ambient vision limitations</li> <li>• Rapid weather change</li> </ul>	
4. Vehicular factors		
<ul style="list-style-type: none"> <li>• Tire and wheel problems</li> <li>• Brake problems</li> <li>• Engine system failures</li> </ul>	<ul style="list-style-type: none"> <li>• Vision obscured</li> <li>• Vehicle lighting problems</li> <li>• Total steering failure</li> </ul>	

Sabey & Taylor (1980) describe the results of a study conducted by the Transport and Road Research Laboratory in the UK, the principal aim of which was to identify the main contributory

factors involved in highway accidents. A response team on call 24 hours a day collected accident data including evidence at the scene and road user interviews. The study covered a total of 2130 accidents. Sabey & Taylor concluded that:

- 41% of the drivers involved were judged to be at fault;
- in 95% of the accidents, driver, pedestrian error and impairment were identified as the main contributory factors;
- in 28% of the accidents, road and environmental factors were identified as contributory factors;
- in 8.5% of the accidents, vehicle features were identified as contributory factors; and
- in 65% of the accidents, the road user was identified as the sole contributor

In addition to the results presented above, the following categories of human error involved in the accidents analysed were identified:

1. Perceptual errors
  - Looked but failed to see
  - Distraction or lack of attention
  - Misjudgement of speed or distance
2. Lack of skill
  - Inexperience
  - Lack of judgement
  - Wrong action or decision
3. Manner of Execution
  - a) Deficiency of actions: too fast, improper overtaking, failed to look, following too close, wrong path.
  - b) Deficiency in behaviour: irresponsible or reckless, frustrated, aggressive.
4. Impairment
  - Alcohol
  - Fatigue
  - Drugs
  - Illness
  - Emotional Distress

Additionally, the following road environment contributory factors were also identified:

1. Adverse road design
  - Unsuitable layout, junction design

- Poor visibility due to layout
2. Adverse environment
    - Slippery road, flooded surface
    - Lack of maintenance
    - Weather conditions, dazzle
  3. Inadequate furniture or markings
    - Road signs, markings
    - Street lighting
  4. Obstructions
    - Road works
    - Parked vehicle, other objects

Finally, the following vehicle related contributory factors were also identified: tyres; brakes; steering; lights; mechanical failure; electrical failure; defective load; windscreen; poor visibility; overall poor condition; and unsuitable design.

The studies described by Treat et al (1977) and Sabey & Taylor (1980) represent the first attempts reported in the literature to identify and classify driver errors and contributory road system features within the road transport domain. Probably the most widely reported error-related study was conducted by Reason et al (1990) who investigated the distinction between errors and violations committed by drivers. Reason et al (1990) developed the Driver Behaviour Questionnaire (DBQ), a 50-item questionnaire comprising five classes of aberrant driver behaviour: slips; lapses; mistakes; unintended violations; and deliberate violations. Examples of the DBQ items are presented in Table 4.2 (adapted from Reason et al, 1990). The items in the questionnaire were designed to vary in two respects: the type of behaviour indicated and the degree of risk to other road users (Reason et al, 1990). The three behaviour categories were slips and lapses, mistakes and violations. The three risk categories used were:

- A. No risk to other road users;
- B. Some possibility of risk to others; and
- C. A definite risk to others.



Table 4.2. Examples of DBQ items (Source: Reason et al, 1990)

Item	Behavioural type	Risk type
Attempt to drive away from traffic lights in third gear	Slip	A
Misjudge your gap in a car park and nearly (or actually) hit adjoining vehicle	Mistake	B
Take a chance and cross on lights that have turned red	Violation	C
Lost in thought or distracted, you fail to notice someone waiting at a zebra crossing, or a pelican crossing light that has just turned red	Unintended Violation	C
Drive with only 'half an eye' on the road while looking at a map, changing a cassette or radio channel etc	Slip	C
Hit someone when reversing that you had not previously seen	Mistake	B
'Race' oncoming vehicles for a one-car gap on a narrow or obstructed road	Violation	C
Forget when your road tax/insurance expires and discover that you are driving illegally	Unintended Violation	A

Reason and colleagues asked a sample of 520 drivers to anonymously rate the frequency with which they had committed the various errors described in the DBQ. In order to identify the most commonly occurring driver aberrant behaviours, the 50 items contained in the DBQ were ranked according to their mean reported frequencies. As a result, the following most frequently reported aberrant behaviours were identified:

1. unknowingly speeding;
2. disregarding speed limits at night;
3. failing to give way to a bus;
4. getting into the wrong lane at a roundabout; and
5. forgetting the current gear.

Additionally, the results indicated that the least frequently reported aberrant behaviours from the DBQ were:

1. overtaking on the left of motorway;
2. disregarding traffic lights late at night;
3. ignoring give way signs;
4. driving the wrong way down a wrong way street; and
5. attempting to drive away without switching the ignition on.

Factor analysis of the data identified three factors: violations, dangerous errors and 'silly errors' (trivial slips and lapses). The highest loaded items in the violations category included disregarding speed limits late at night, getting involved in unofficial races, driving too close and flashing for the car ahead to go faster, driven by frustration to overtake in risky circumstances, overtaking on the inside and disobeying a red light. The highest loaded items on the second factor, dangerous errors, included failing to notice pedestrians crossing, misjudging the speed of an oncoming vehicle when overtaking, misjudging crossing interval when turning right, failing to check mirror before maneuver, overtaking without first checking mirror and failing to notice someone waiting at a controlled crossing. The highest loaded items on the third factor, so-called silly errors, included forgetting where one's car is parked, exiting on the wrong road from a roundabout, getting into the wrong lane prior to a roundabout or road junction and missing one's exit on a motorway. Multiple regressions were then used to calculate which of the section 1 and 3 elements of the DBQ were the best indicators of the three factors.

Reason et al (1990) reported that older drivers and those who rated themselves as law-abiding reported fewer violations, whilst those drivers with higher annual mileages and also those whose driving is more affected by mood reported more violations. Additionally, male drivers reported committing more violations than did female drivers and those participants who believed themselves to be better drivers also reported committing more violations than did drivers with more modest self-appraisals. The results also indicated that the more affected by mood a person is, the more likely he or she is to commit dangerous errors. Also, more frequent motorway users reported making more dangerous errors. Predictably perhaps, participants who rated themselves as safe drivers reported making fewer dangerous errors, whilst participants who rated themselves as error-prone reported making more dangerous errors. In the third factor, 'silly errors', those participants who reported that mood affected their driving also reported more silly errors, and those who rated themselves as error prone also reported making silly errors more frequently. Finally, Reason et al (1990) reported that female drivers reported making significantly more silly errors than did male drivers. Reason et al (1990) also reported age-by-sex relationships for violations, errors and lapses. The data indicate that violations, errors and lapses committed by male and female drivers all decreased with increasing age. In conclusion, Reason et al (1990) proposed that there is a distinction between errors and violations and that they can be classified as two different classes of driver behaviour with different underlying psychological processes.

The DBQ questionnaire used by Reason et al (1990) has since been the subject of much investigation within the road transport domain. Blockey & Hartley (1995) used the DBQ questionnaire to investigate the distinction between errors and violations in Australian road transport. A total of 135 participants completed the questionnaire. The most frequently reported behaviours in Blockey & Hartley's study were:

1. Unknowingly speeding;
2. Overtaking on the inside;
3. Driving with half an eye on the road;
4. Disregarding the speed limit late at night; and
5. Being distracted and having to break hard.

The five least frequently reported behaviours were:

1. Ignoring give way signs;
2. Failing to see a pedestrian stepping out;
3. Forgetting when road tax/insurance expires;
4. Deliberately going the wrong way down a one way street; and
5. Trying to drive off without first having switched on the ignition.

Similar to the work of Reason et al (1990), a factor analysis produced three factors: general errors, dangerous errors, and dangerous violations. The general errors category was mostly composed of slips, mistakes and unintentional violations of mixed risk. The dangerous errors category was composed of slips, mistakes and unintentional violations deemed to pose a definite risk to other road users. The third factor, dangerous violations, comprised violations almost all of which were deemed to pose a definite risk to other road users (Blockey & Hartley, 1995). Multiple regressions of the data indicated that those participants who reported being convicted of offences other than speeding, dangerous driving, or driving under the influence of alcohol obtained higher scores for factor 1, general errors.

Younger drivers were found to commit more dangerous errors, and the frequency of these errors was found to decrease with age. Interestingly, it was also found that females reported committing more dangerous errors than males. For the third factor, dangerous violations, increased age was associated with fewer dangerous violations. Male drivers reported a higher frequency of dangerous violations than did females, drivers who had previously been convicted for speeding estimated that they drove more kilometers per week and reported that most of their driving was interstate-based also obtained high factors 3 scores. There was no significant difference between male and females for the first factor, general errors. However, female drivers reported committing more dangerous errors (factor 2) than male drivers and male drivers reported making significantly more dangerous violations (factor 3) than did female drivers. A factorial distinction between errors and violations was found like that reported by Reason et al (1990).

Parker, Reason, Manstead & Stradling (1995) used a shorter version of the original DBQ to further explore the error-violation distinction highlighted by the two studies above. Over 1600 drivers were surveyed using the DBQ and the three-factor structure identified by Reason et al (1990) was confirmed. Further, to assess the reliability of the DBQ, 80 participants were asked to complete it again seven months later. The results indicate that the shorter version of the DBQ is reliable. Only self-rating as a driver and gender were found to be predictive of a tendency to make errors. Males were more likely to report high error rates than females and those who rated themselves as poor drivers reported making more errors. Again, gender and self-rating of driving ability were the only significant indicators of the lapse factor. Females reported committing more lapse-based errors than males, and those who rated themselves as poor drivers also reported making more lapse-based errors. Indicators of violations included participant age, gender, self-rating of driving ability and annual mileage. Parker et al (1995) concluded that the distinction between errors, violations and lapses reported by Reason et al (1990) was confirmed. Additionally, Parker et al (1995) reported that a tendency to commit violations was statistically significant as a predictor of accident involvement and, in order to improve road safety, violations should be addressed and reduced. According to Parker et al (1995) violations are the type of behaviour most

closely linked with accident involvement and because they are socially and motivationally based may be more likely to be mitigated through persuasion rather than training (Parker et al, 1995).

In yet another replication of the original DBQ study, Aberg and Rimmö (1998) used a sample of Swedish drivers covering a broader age range than previous studies. Additionally, 25% of the sample comprised young drivers between 18 and 24 years old. The original DBQ was translated into Swedish and additional items generated by a sample of Swedish drivers were added. The modified Swedish version of the DBQ containing 104 items was then completed by 1429 participants. The five most frequently reported driver behaviours were.

1. Speeding when overtaking;
2. Disregarding speed limit to follow traffic flow;
3. Exceeding speed limit during low traffic;
4. Speeding up at traffic lights; and
5. Misjudge distance.

Initial factor analysis of the data confirmed the three-factor solution reported by Reason et al (1990) and Parker et al (1995). A factor analysis was conducted on the data derived using the Swedish version of the DBQ. Aberg and Rimmö (1998) reported that the following four factors explained the total variance of driver errors in Sweden: violations, mistakes, inattention and inexperience.

In a follow up study, Rimmö and Aberg (1999) used a two part self-report questionnaire designed to assess sensation seeking levels and driver aberrant behaviour. Sensation seeking was defined as, “the seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal and financial risks for the sake of experience” (Zuckerman, 1994; cited in Rimmö and Aberg, 1999). The survey was administered to young adult Swedish drivers (aged 18 – 27 years) in order to investigate sensation seeking, the tendency to engage in risky behaviours, four types of aberrant driving behaviour (violations, mistakes, inattention and inexperience errors), traffic offences and accident involvement. Four factors were extracted from the DBQ questionnaire data: violations, inexperience errors, mistakes and inattention errors. The results indicate that there is a differential relationship between different aspects of sensation seeking and aberrant driver behaviour. In conclusion, Rimmö and Aberg (1999) reported that their findings corresponded well with the distinction between violations and errors found by Reason et al (1990).

Kontogiannis, Kossiavelou and Marmaras (2002) used a modified version of the DBQ to survey over 1400 drivers in Greece to identify aberrant driving behaviours. Three types of violations were identified, including highway code, aggressive and parking violations. Mistakes and lapses were identified as the main forms of errors. Two additional classes of behaviour were also identified: low preparedness/negligence and communication errors or social disregard. Accident liability was predicted using drivers’ self-reported tendency to commit Highway Code violations. It was found that aggressive violations were significantly related to involvement in speeding convictions and law breaking, whilst highway code violations were related to speeding convictions. In conclusion Kontogiannis, Kossiavelou and Marmaras (2002) report that errors are more amenable to ergonomic solutions such as driver interface redesign, memory aids and retraining, while violations require changes in attitudes and social norms.

Xie and Parker (2002) used the Chinese Driving Questionnaire (CDQ), a modified version of the DBQ with an extended set of violations that are of relevance to China. Five hundred and twenty completed questionnaires were analysed. Xie and Parker reported that the six most commonly reported behaviours were all violations, and a factor analysis confirmed the distinction between lapses and errors and intentional violations.

Another study designed to replicate the work of Reason and colleagues was conducted by Lajunen, Parker & Summala (2004) to investigate the equivalence of the DBQ factor structure within samples of British, Dutch and Finnish drivers. In conclusion, Lajunen et al (2004) reported that the factor structures of the DBQ were very similar, but not identical in the three countries investigated.

As described above, the literature indicates that much of the human error-related research in the road transport domain has involved the DBQ to identify the different error types made by drivers. This research is useful for a number of reasons: retrospectively, to indicate which types of errors occur most frequently in road transport, to determine the most commonly occurring errors in different driver groups, and also to derive predictive associations between different driver groups and different error types. However, the majority of the research conducted using the DBQ has been used for error classification purposes only and has neglected both the multiple causal factors associated with the various errors described or the development of measures designed to mitigate the different errors reported. In addition, the data from the DBQ is entirely subjective, and is based on the accurate recall of past errors.

In addition to the DBQ-related research, a number of other human error-related studies have been conducted within road transport. In an investigation into the types of human error involved in rear-end collisions in Japan, Hiramatsu and Obara (2000) analysed the pre-crash behaviour involved in rear-end accidents recorded in macro traffic accident data during 1997. The human errors of the primary party (driving the striking vehicle) in four types of pre-crash behaviour were analysed. The following findings emerged:

- in accidents where the striking vehicle was cruising and the struck vehicle was stopped, 'inattention due to internal or to external reasons' accounted for 76.3% of the total accidents;
- in accidents where the striking vehicle was cruising and the struck vehicle was decelerating, 'inattention due to internal or to external reasons' accounted for 65.9% of the total accidents, and 'not looking carefully' accounted for 25.2%;
- in the accidents where the striking vehicle was decelerating and the struck vehicle was stopped, 'inattention due to internal or to external reasons' accounted for 64.4% of the total accidents, and 'improper operation' accounted for 13.7%; and
- in the accidents where the striking vehicle was starting off and the struck vehicle was stopped, 'inattention due to internal or to external reasons' accounted for 34.4%, 'not looking carefully' accounted for 28% and 'improper operation' 28.9%.

Following this investigation, simulations of rear-end collision scenarios were conducted using the Monte Carlo method to estimate the probability of rear-end collision occurrence. The probability was estimated from the total annual mileage and actual number of rear end collisions in Japan. The probability of a following vehicle striking a stopped vehicle was estimated at about one per 600,000 stops and the probability of a following vehicle striking a decelerating vehicle was estimated as about one per 1,500,000 decelerations. In conclusion, Hiramatsu and Obara (2000)

recommend that measures for preventing rear end collisions are required, including systems for reducing driver workload and for compensating for mistakes in recognition, judgement and operation.

Rumar (1990) discusses errors of detection i.e. failing to see other road users in time. Rumar (1990) defines errors of detection as “failure by a road user to detect another road user in time to be able to avoid him or her while successfully completing a planned course of action”. Rumar identified a lapse of cognitive expectation (failure to scan for other road users or look in the appropriate direction) and a difficulty with perceptual thresholds as the two most important causes of driver detection errors. According to Rumar, Treat (1980; cited in Rumar, 1990) ranked the main types of human errors involved in collisions between road users as follows:

1. Recognition errors.
2. Decision errors.
3. Performance errors.
4. Other.

In addition, Treat (1980) divided the errors presented above further, on the basis of frequency of occurrence, into the following groups.

1. Improper lookout.
2. Excessive speed.
3. Inattention.
4. False assumption.
5. Improper manouvre.
6. Internal distraction.

According to Rumar (1990), failure to detect another road user is the main source of error in road transport and it belongs to two main categories of error, cognitive detection errors and perceptual detection errors. Cognitive detection errors result from incomplete or erroneous road user models of the road traffic environment and of the different dynamic elements within the environment, leading to inappropriate expectations resulting in late or failed detections (Rumar, 1990). Perceptual detection errors arise due to the lack of evolutionary stimulus patterns in the road traffic environment (e.g. cars have no perceivable internal motion such as the leg movements associated with animals; Rumar, 1990). In closing, Rumar suggests that it may be inefficient to educate or train road users to improve their attentional capacity, rather he proposes that countermeasures involving stimulus enhancement have proved to be efficient in the past and that enhancing road user conspicuousness can lead to the eradication of both forms of detection error.

In addition to the large body of research surrounding error classification, researchers have also considered the use of human error models in the design and evaluation of road transport systems. For example, Hale, Stoop & Hommels (1990) investigated the predictive utility of human error models in the design of road transport systems. Hale et al (1990) concluded, amongst other things, that cognitive psychologists need to collect and classify accident and incident data in a way that allows an understanding of the design features that are associated with the breakdown of production rules, and also collect and classify information about human recovery from errors so

that factors that lead to error recovery can be identified. Hale et al (1990) also suggested that models such as GEMS can be used to predict many potential errors within the road transport domain. However, while this is useful, Hale et al (1990) point out that so many potential errors may be identified that the designer does not know which ones to address. Hale et al (1990) suggested that human error models and theories currently lack systematic information about human error recovery, which types of errors are more (and less) likely to be noticed and recovered from by drivers, or compensated for by other drivers. They also suggested that to provide useful indications of the types of predictable error which are more likely to lead to problems, further data collection on accidents is required.

### **Elderly Drivers and Errors**

Considerable attention has been focused on elderly drivers and error. Di Stefano & Macdonald (2003) investigated the nature of errors made by elderly drivers during licence review tests to determine, amongst other things, the types of errors indicative of elderly driver competence. From a review of 533 elderly driver road licence review tests, errors were recorded in the following six categories: intersection negotiation, lane changing diverging, position and speed, low speed manoeuvre, safety margin and car control. A summary of the errors identified is presented in table 4.3. For lane changing and low speed manoeuvres the two most frequent error types were a failure to look back over the shoulder when required, and a failure to check mirrors when required. The most frequent intersection negotiation errors were a failure to check mirrors and neglecting to use turn indicators. In relation to the maintenance of appropriate vehicle position and speed, poor positioning on 'clearways' without lane markings and poor lanekeeping were the most frequent errors.

The results indicate that errors relating to maintenance of safety margins and also vehicle control were less frequent. The most frequent error related to safety margin maintenance was driving too close to parked cars, while the most frequent vehicle control errors were related to the steering of the vehicle. In conclusion, Di Stefano & Macdonald reported that test outcome was invariably determined by whether the license testing officer was required to intervene during the test in order to maintain safety, which was indicative of a 'hazardous error' occurrence. Additionally, Di Stefano & Macdonald reported that 56% of hazardous errors occurred during lane changing, merging or intersection negotiation. The strongest predictors for test pass or failure were performance scores for intersection negotiation and for maintenance of position and speed, followed by safety margin.

Table 4.3. Elderly driver errors (Source: Stefano &amp; Macdonald, 2003).

Error Types	Low speed manoeuvres	Intersection negotiation	Lane changing	Maintenance of appropriate position and speed	Maintenance of safety margins	Car control
Fail to turn head back over shoulder	45% (1.4)	N/A	62% (3.4)			
Fail to check mirrors	13% (1.3)	69% (6.5)	26% (1.9)			
Fail to use turn indicators	12% (1.3)	49% (2.7)	31% (1.8)			
Poor gap selection	11% (1.1)	N/A	10% (1.1)			
Poor positioning of vehicle	10% (1.2)	N/A	N/A			
Poor gap selection/judgement	N/A	43% (1.9)	N/A			
Poor position on road when turning	N/A	39% (2.1)	N/A			
Fail to obey sign/signal	N/A	30% (1.6)	N/A			
Poor approach (speed before an intersection)	N/A	14% (1.8)	N/A			
Poor speed control for lane changing	N/A	N/A	2% (1.1)			
Unlaned clearway				40% (3.2)		
Lane keeping				34% (2.6)		
Too slow for conditions				31% (3.0)		
Exceeding speed limit				17% (2.0)		
Too fast for conditions				3% (2.5)		
Parked cars					15% (1.6)	
Following distance					4% (1.2)	
Stop too close					2% (1.2)	
Too close to object					2% (1.2)	
Steering						12% (2.2)
Braking						5% (2.0)
Accelerator						3% (2.4)
Gear choice						1% (1.7)

Dobbs, Heller, & Schopflocher (1998) conducted a comparative study of the driving errors made by 'normal' older drivers, older drivers with clinically significant declines in mental abilities and also young 'normal' drivers. Drivers from each group completed a clinical driving consultation, a battery of research tasks, a driving questionnaire, and finally a specifically designed road test consisting of 37 manoeuvres that were selected based on their previous implication in older driver crashes. During the road test, the evaluator recorded descriptions of the type and severity of driver errors observed and each error was rated as 5, 10 or 51 depending on severity (51 = automatic fail of the test). Amongst other results, Dobbs et al (1998) developed a list of 150 different errors that were recorded during the trials. These errors were then sorted into 13 general categories of driver error. The 13 error categories and examples for each category are presented below (Source; Dobbs et al, 1998):



1. Extreme positioning error e.g. driving on the shoulder.
2. Minor positioning error e.g. driving too close to lane markings.
3. Turning position error e.g. wide turns or cut turns.
4. Stop positioning error e.g. stopping too close or too far back.
5. Scanning error e.g. no shoulder checks.
6. Over cautiousness e.g. driving too slowly.
7. Aggressive maneuver e.g. risky turns.
8. Rolled stop e.g. failing to come to a complete stop at a sign/signal.
9. Speed error e.g. driving over the posted speed limit.
10. Vehicle control e.g. shaky steering.
11. Poor habits e.g. one handed steering.
12. Signal error e.g. late/early to signal.
13. Hazardous error e.g. dangerous errors regardless of the type of maneuver involved.

In conclusion, Dobbs et al (1998) reported that older drivers with cognitive impairments made significantly more hazardous errors than did the 'normal' older and young drivers. Half of all the hazardous errors recorded occurred during lane changing, merging, and approaching intersections. Twenty one percent of the hazardous errors occurred during left turns, 15% occurred when the drivers failed to stop, 6% occurred during right turns and 8% occurred during stopping manoeuvres. Dobbs et al (1998) also reported that hazardous errors, scanning errors, turn positioning errors, minor positioning errors and over-cautiousness errors were indicative of declines in driver competence.

#### **4.2.2 Systems Perspective Based Human Error Research**

The literature reviewed indicates that the majority of human error-related research conducted to date in road transport has been conducted from a person-approach perspective. The research described in the previous section has a common focus on the identification and classification of the nature or types of errors and unsafe driver behaviours made by individual drivers. The results of the literature review indicate that, within the road transport domain, the systems perspective-approach to human error has received significantly less attention than the person-approach to error. That said, in recent years there appears to have been a marked increase in systems perspective based research, and the systems-approach to error is beginning to receive increased attention from the road transport research community. The following section presents an overview of the systems perspective-based human error research conducted in the road transport domain to date.

In order to demonstrate the utility of a systems perspective approach in the analysis of road transport traffic accidents, Wagenaar & Reason (1990) identified two distinct classes of causes in road traffic accident scenarios, *token* causes and *type* causes. Token causes refer to the direct causes of the accident that occur immediately prior to the accident, while type causes refer to those causes that might have been present in the system for a long time (similar to the latent conditions

described in the systems perspective model). Wagenaar & Reason (1990) suggest that to be effective, accident countermeasures should focus on the identification of *types* rather than *tokens*, and that accident analysis should extend beyond the identification of those events that immediately precede accidents. In the article, Wagenaar & Reason present a systems perspective-based analysis of the following hypothetical accident scenario:

*“A white BMW is approaching an unsignalised intersection in a suburban area of a large city. A blue Mazda is approaching from the right. The two cars collide at low speed, but both cars are irreparable. The driver of the BMW is considered blameworthy because she did not give way to the car coming from the right. A closer analysis of the case reveals that the driver of the Mazda was a 17 year old woman who lacked experience and who had caused another accident two months before. Cars had been parked along the streets, all the way up to the corner, blocking the view of both drivers. The Blue Mazda was not very conspicuous. Drivers had complained about the number of cars parking in those streets. The BMW was driving on a road that had right of way at four previous intersections, and it had already been proposed to extend the right of way to this intersection. Unfortunately the town council had denied the proposal”* Wagenaar & Reason (1990).

The systems perspective analysis of the accident described above is presented in Figure 4.1. The schematic representation of the accident demonstrates how a systems perspective in the road transport domain can be effectively used in the analysis of incident and accident scenarios. According to the analysis, the city planners, licensing authorities, drivers, parked cars, twilight conditions, and the colour of the Mazda are all implicated in some way in the incident. However, within the real-world, blame would probably be attributed to the driver of the BMW. Wagenaar & Reason (1990) suggested that remedial measures can be proposed at each of the different levels in the systems perspective model, namely:

#### 1. Defences

- impose bright colours for cars;
- mandatory daytime headlight use; and
- impose parking limitations near the intersection.

#### 2. Unsafe acts

- teach drivers to slow down at intersections; and
- teach drivers to watch out for other traffic, even when they have right-of-way.

#### 3. Psychological pre-cursors

- mark unprotected intersections with orange flashing lights; and
- force drivers to take additional, specific, error-correcting lessons after causal accident involvement.

#### 4. Failure types

- install a consistent right-of-way system;
- abolish unprotected intersections;
- adopt a policy of reacting positively to public complaints; and
- improve general driver education.

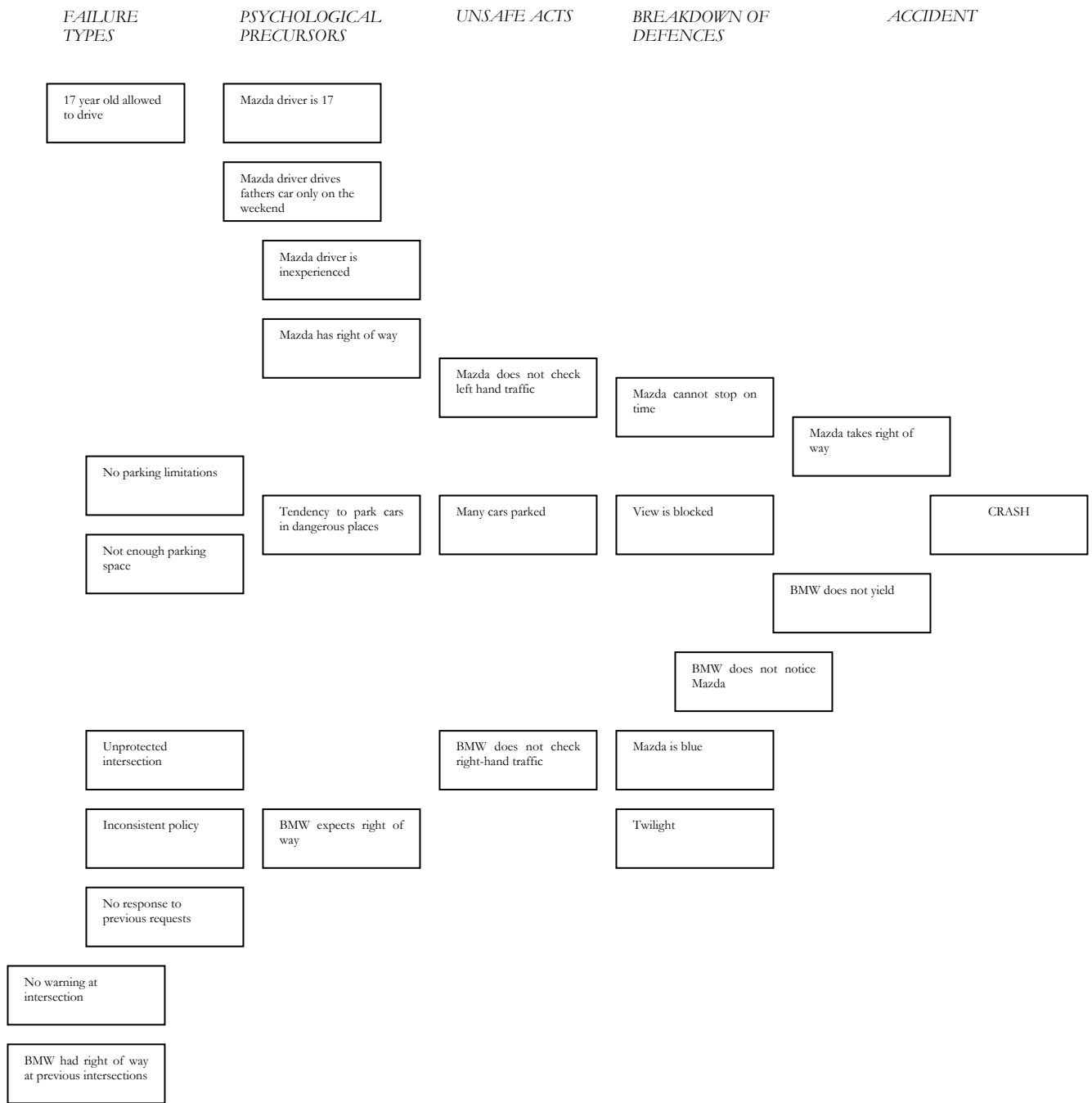


Figure 4.1. Systems perspective of BMW-Mazda Incident (Source: Wagenaar & Reason, 1990).

Wagenaar & Reason (1990) also identified the following different types of remedies: defence improvements (changes that may prevent an accident even when unsafe acts are committed); changes that prevent the commission of unsafe acts; measures designed to prevent the emergence of psychological precursors; and those measures that prevent failure types from occurring in the first place.

Wagenaar & Reason (1990) also identified the following general failure types that precede accidents:

- hardware defects (e.g. poorly designed intersections, unsafe car designs);
- incompatible goals (speed limits increase safety but incur a loss of time);
- poor operating procedures (poor or illogical traffic regulations, e.g., on roundabouts);
- poor maintenance (roads in poor condition, street lights broken, too many defective cars);
- inadequate training (many drivers too young, inadequate driver qualification testing);
- conditions promoting violations (unnecessary traffic lights, lack of police control, road repairs causing long delays, insufficient parking space); and
- lack of organisation (no systematic traffic policy, no systematic collection of accident statistics, no organised reaction to public complaints).

In conclusion Wagenaar & Reason proposed that those involved in accident prevention should ask which failure types are the most frequent causes in road traffic accidents, and also which are the most promising targets for preventative measures. As an educated guess, they suggest that incompatible goals, conditions promoting unsafe behaviour and organisational inadequacy are probably the most important of the failure types identified. Wagenaar & Reason also suggested that current accident statistics do not permit the analysis of the different failure types involved. Their article provides a unique insight into the potential application of a systems perspective approach to error and the analysis of road traffic accidents in the road transport domain and also demonstrates how remedial measures could be developed and proposed as the result of such analyses.

Ljung, Huang, Aberg and Johansson (2004) describe a systems perspective-based structured accident analysis methodology developed specifically for road transport. The Driver Reliability and Error Analysis Method (DREAM; Ljung, 2002) is an adaptation of the Cognitive Reliability and Error Analysis Method (CREAM; Hollnagel 1998) and was developed specifically for the analysis of road traffic accidents (Ljung et al, 2004; Huang & Ljung, 2004). The DREAM approach is based on the assumption that the causes of accidents are a function of the interactions that take place between the man, technology and organisations (MTO) within the road transport domain. DREAM uses common performance conditions (CPCs) and a classification scheme to analyse road traffic accidents and incidents. The technique offers an analysis of both the context within which the accident occurred and also an analysis of the accident itself, in terms of the causal factors and errors involved.

Recent research using the DREAM approach was conducted to test the utility of analysing near-miss reports in road transport and to identify and classify the causal factors involved in road traffic accidents. As part of a Swedish project entitled 'Factors Influencing the Causation of Incidents and Accidents' (FICA; Ljung, Huang, Aberg and Johansson, 2004) near miss data was collected and analysed using the DREAM approach. The study used diaries and focus groups to collect near miss data from four groups of drivers: private car drivers driving at least four days a week; bus and taxi drivers; drivers from a range of haulage contractors; and professional traffic observers, including traffic police and driving instructors. A total of 62 near-miss incidents were analysed using DREAM. The near misses were classified according to the Swedish Road Administration's accident type categories.

This classification led to the following breakdown of accident types:

- intersection (14);
- turning (10);
- rear-end (5);
- pedestrian (5);
- meeting (3);
- overtaking/Lane change (20); and
- single (5).

The following DREAM example analysis is taken from the study conducted by Ljung, Huang, Aberg and Johansson (2004). The first step in the analysis involves creating a narrative of the accident under analysis. Ljung et al (2004) present the following narrative:

*Car driver is driving home from work. A friend from work is riding with him, and they're talking. They get to an intersection in a residential area where the right-hand rule applies, but 95 % of all traffic comes from the same direction that the car driver approaches from. The driver proceeds with a left turn, only to discover half way through that there's a car coming from the right that he should have stopped for according to the right hand rule. The other car drives slowly, and the driver of the first car accelerates to get out of the way.*

Additionally a sketch diagram of the event is created. The next step involves analysing the CPCs related to the incident. The CPC analysis is presented in Table 4.4.

Table 4.4. Common Performance Conditions Analysis (Source: Ljung, Huang, Aberg and Johansson, 2004)

CPC	Parameters	Evaluation
Traffic Environment	Essential factors:	No obvious risk factors (0)
	Complexity: <i>Single lane, intersection</i>	Moderately complex (0)
	Information:	Adequate (0)
Driver Environment	Physical environment:	Unknown
	HMI – Individual interfaces	Unknown
	HMI – Combination of interfaces	Unknown
Driving conditions	Road surface/Friction:	Good (0)
	Visibility (general):	Good (0)
	Visibility (obstructing elements): <i>Oncoming traffic from the right is blocked by shrubberies</i>	Poor (-)
Available time	Type of Traffic environment:	Urban (-)
	Speed: <i>30 km/h posted</i>	< 50 km/h (+)
	Traffic density:	Light traffic (0)
	Time of day (accident rate): <i>16:30, Wednesday, 2.7 acc/hr (national statistics)</i>	High accident level (-)
	Time of day (diurnal rhythm)	Within rhythm
Number of simultaneous goals		Fewer than capacity
Experience and Training	Driver experience: <i>21 yrs licence, 1600km/month</i>	Adequate, rich experience (+)
	Driver acquaintance with environment:	Passes every day (+)
	Driver acquaintance with the vehicle:	Adequate, rich experience (+)
	Driver education (procedures, regulations, vehicles):	Adequate (0)

Next, the phenotypes (ways in which dysfunctional behaviour manifests itself e.g. action too late, failed to perform action) and genotypes (causal factors) are classified. For the incident under analysis, the phenotype *Timing: Omission* is specified (Ljung, Huang, Aberg and Johansson, 2004). Once the phenotype is determined, the analyst uses the DREAM linking table to identify possible genotypes and antecedents (causal factors). The possible antecedents for the incident under analysis are presented in Table 4.5.

Table 4.5. Antecedents analysis (Source: Ljung, Huang, Aberg and Johansson, 2004).

General antecedent	Specific antecedent	General consequent	Specific consequent
Communication failure Information problems Inadequate judgement Inattention Inadequate plan Missed observation	Trapping error	Timing	Too early Too late Omission

From the possible antecedents identified, missed observation is deemed the most applicable, as the driver did not see the other car approaching (Ljung, Huang, Aberg and Johansson, 2004). Next, the analyst uses the DREAM classification scheme to identify antecedents and consequents related to the missed observation antecedent. The possible antecedents related to missed observation are presented in Table 4.6.

Table 4.6. Missed observation antecedents analysis (Source: Ljung, Huang, Aberg and Johansson, 2004).

General antecedent	Specific antecedent	General consequent	Specific consequent
<i>Technical failure</i> Inadequate judgement Inadequate plan Distraction Functional impairment Missing information	Information overload Noise Multiple signals Parallax	Missed observation	<i>Overlook cue/signal</i> Overlook measurement

From the possible antecedents related to missed observation, the general antecedents distraction (driver was talking to passenger) and missing information (driver could not see other car due to shrubby blocking his line of sight). Next, the analyst uses the classification scheme to identify the possible antecedents related to distraction and missing information. These are presented in Tables 4.7 and 4.8.

Table 4.7. Distraction antecedents analysis (Source: Ljung, Huang, Aberg and Johansson, 2004).

General antecedent	Specific antecedent	General consequent	Specific consequent
<i>Technical failure</i> <i>Communication failure</i>	Passenger Competing activity (cell phone, navigation system etc) Stir/disturbance	Distraction	Task suspended Task not completed Goal forgotten Loss of orientation

Table 4.8. Missing information antecedents analysis (Source: Ljung, Huang, Aberg and Johansson, 2004).

General antecedent	Specific antecedent	General consequent	Specific consequent
Design failure Inadequate quality control	Hidden information Noise	Missing information	No information Incorrect information Misunderstanding Language error

At this point, no further antecedents can be specified, and so the analysis ends. The output can then be put together in a graphical description of the causes of the near miss. An example output for this incident is presented in Figure 4.2 (Source: Ljung, Huang, Aberg and Johansson, 2004). In Figure 4.2 the causes (genotypes) are a missed observation caused by passenger distraction and missing information arising from a design failure and the phenotype (manifestation) is an error of omission.

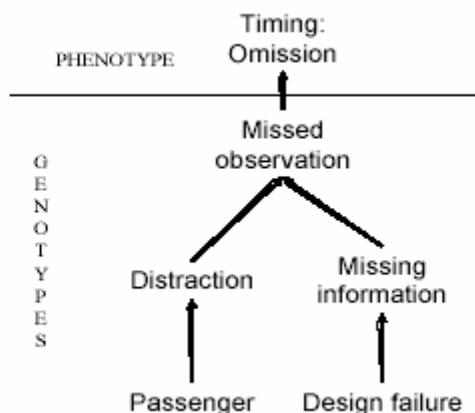


Figure 4.2. DREAM analysis output (Source: Ljung, Huang, Aberg and Johansson, 2004).

According to Ljung, Huang, Aberg and Johansson (2004) the results indicate that a combination of diaries and focus groups for studying near misses and incidents yields high quality data.

Wierwille, Hanowski, Hankey, Kieliszewski, Lee, Medina, Keisler & Dingus (2002) describe a comprehensive study at the Virginia Tech Transportation Institute to investigate the nature and causes of driver errors and their role in crash causation, to develop driver error taxonomies and to develop recommendations for improvements in traffic control devices, roadway delineations and accident reporting forms. The research conducted included a literature review, the development of a driver error taxonomy, an investigation of critical incidents at 31 roadway sites and the development of infrastructure-related countermeasures designed to reduce infrastructure-related incidents. The research culminated in the following:

- development of driver error taxonomies;
- development of a taxonomy of contributing factors designed to identify the nature and the causes of driver errors;

- identification of the usefulness of applying tree diagrams for viewing accident data;
- recommendations for improving accident report forms and coding systems. A number of problems with existing accident report systems were identified, including inconsistency across jurisdictions and a lack of precision in the data recorded. In response to the problems identified, a number of recommendations were made, including that a uniform coding scheme to suit the needs of state and national databases be developed, that human factors improvements be made to existing reporting forms and software, that principal and contributory factors and driver errors should be included on reporting forms, that re-transcription is eliminated and that officer suggestions for remedial measures related to infrastructure and driver problems and improvements to accident reporting forms are encouraged;
- development of a site evaluation methodology designed to enhance the understanding of the contributing factors associated with accidents, incidents and driver errors, and the relationship between driver errors and infrastructure;
- development of a scale for grading traffic event severity. An eight-point traffic event rating scale was developed designed for use in the assessment of the severity of critical incidents and accidents;
- development of probability models for incidents and accidents; and
- development of a clustering approach designed to identify infrastructure problems.

The development of driver error taxonomies involved analysing national and state accident databases (e.g. Fatality Analysis and Reporting System (FARS), the Highway Safety Information System (HSIS) and the State Data Program (SDP) and the conduct of focus groups and interviews with drivers regarding critical incidents in which they had been involved. In conclusion, the Contributing Factors taxonomy was developed (see Figure 4.3). Wierwille et al (2002) report that the 'early' Contributing Factors taxonomy seemed to fit most crash situations. According to the taxonomy, there are four different groups of factors that contribute to task performance problems that occur during crashes. These are inadequate knowledge, training and skill, impairment, wilful behaviour, and infrastructure and environment. According to Wierwille et al, these factors combine in different ways to influence driver task performance, which results in a crash.



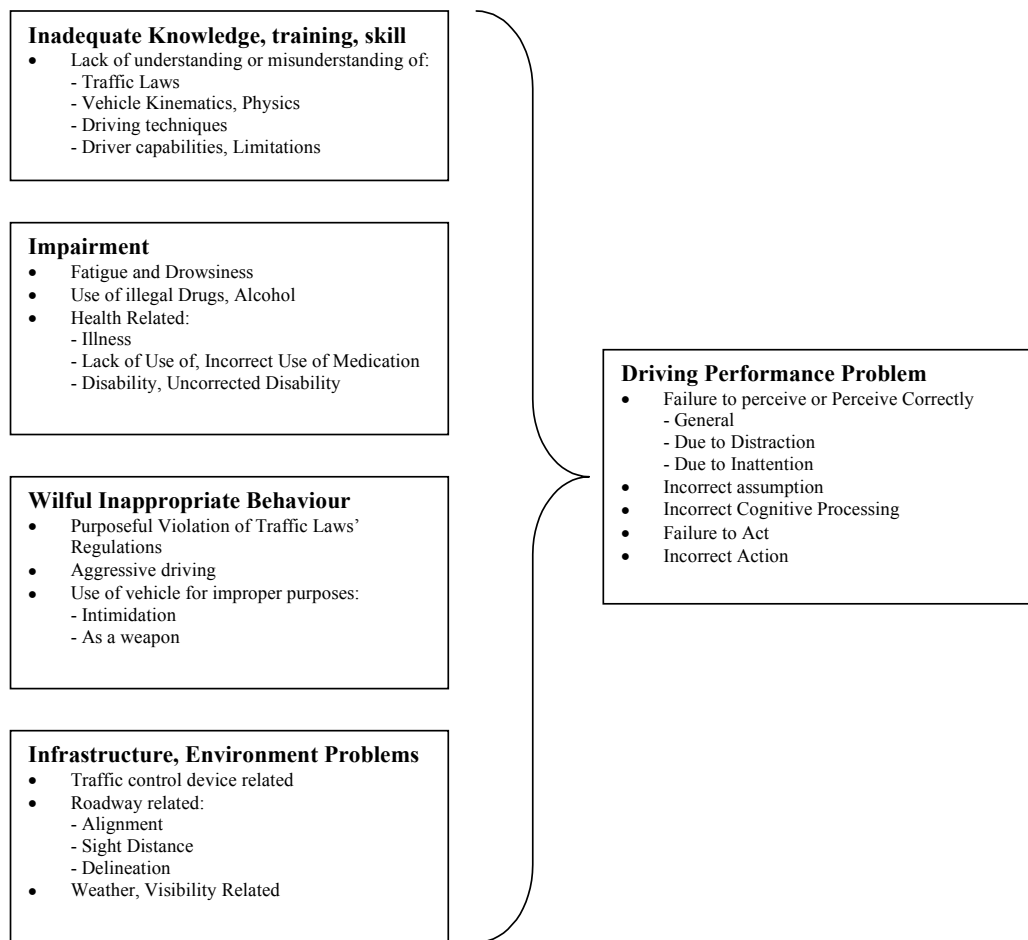


Figure 4.3. Contributing factors taxonomy (Source: Wierwille et al, 2002).

Medina, Lee, Wierwille & Hanowski (2004) describe an on-site surveillance study that was conducted as part of the research program described above. The study involved the use of video camera surveillance to gather critical incident (crashes and near crashes) data at intersections and other roadway sites. Over 1,200 traffic events caused by driver error were recorded at a total of 32 sites. Those incidents in which infrastructure (e.g. signing, signaling, delineation, alignment, and geometry) was identified as a contributory factor were analysed further in order to identify the exact nature of the infrastructure errors involved, and then countermeasures were proposed. A total of 52 critical incidents were analysed. A master sheet which summarised the incident and its contributing factors was developed for each incident. The master sheet included an error type statement, a description of the typical location, a description of a typical example of the error, recommended countermeasures, a description of the standard practice adopted when designing the infrastructure involved, a rating of financial costs associated with the implementation of the proposed countermeasures, and also a description of the other countermeasures that were considered. A total of 43 infrastructure-related incidents were examined further. The driver error statements were classified into one of the five categories presented in table 4.9 (Source: Medina et al, 2004).

Table 4.9. Categories of infrastructure related incidents.

CATEGORY
<b>1. Signals</b>
1.1 Confusing Multiple Signals
1.2 Signals visible
1.3 Signals Creating Bunching
1.4 Uncoordinated Signals
<b>2. Signs</b>
2.1 Signs Readable But Ineffective/Apparently Ignored
2.2 Signs Unclear/Confusing/Missing
2.3 Stop Sign, Confusion Regarding Right-of-Way
<b>3. Alignment and Geometry</b>
3.1 Intersections In Close Proximity To One Another
3.2 Private Entrance/Exits In/Near Intersections
3.3 Short Weaving Sections
3.4 Short Merge/Entrance/Acceleration Lane
3.5 Visibility Difficulties Resulting Directly From Alignment/Geometry
3.6 Visibility Difficulties Resulting From Blockage by other vehicle
3.7 Visibility Difficulties Resulting In Encroachment
<b>4. Delineation</b>
<b>5. Pedestrian and Bicycle Interactions</b>

As a result of the analysis of incidents, the following eight general problem areas were identified:

- larger-vehicle visibility blockage problem;
- pedestrian right of way violations;
- left turns at signalised intersections;
- right-of-way confusion at two-way-stop controlled intersections;
- entrance and exit-lane inadequacies;
- private entrances and exits near an intersection;
- intersections in close proximity to one another; and
- beginning and endpoint control of time-of-day directional lane usage.

In conclusion, Medina et al (2004) reported that infrastructure plays an important part in many traffic conflicts (although they also point out that infrastructure is far from being the sole contributor in most conflicts) and that infrastructure contributes to driver confusion and uncertainty, visual and cognitive workload, and possibly risk taking. Medina et al also concluded that the findings highlighted the importance of conforming to existing standards, and that in many cases recommended practices are not followed.

### 4.2.3 Accident Reporting and Investigation in Road Transport

As is the case in most other safety critical domains, accident reporting and investigation is employed within the road transport domain to collect and analyse crash related data. The data obtained is used to identify crash trends and to inform the development of countermeasures. Unlike other safety critical domains, however, not all accidents taking place within the road transport domain are reported. Only those accidents that the police or other emergency services attend are formally reported by the attending police officers. Other accidents that are either not serious enough for the police to attend or not reported to the police are not reported. When reporting an accident in Victoria, the police complete a standard accident report form. The accident form is designed to collect the following information:

- day, date and time the accident occurred;
- location (e.g. street, road or highway, that the accident occurred on, suburb that the accident occurred in, Melway ref etc);
- type of collision (e.g. collision with vehicle, struck pedestrian, struck animal, collision with fixed object etc);
- information regarding the people involved (e.g. road user type, name, contact address etc);
- information regarding the vehicles involved (e.g. make and model, registration, colour etc);
- diagram of collision scene;
- brief description of collision (with no apportioning of blame);
- environmental conditions (e.g. road surface type, condition, lighting conditions, atmospheric conditions);
- traffic control involved (e.g. intersection signals operating, pedestrian crossing etc);
- driver movement prior to impact (e.g. going straight ahead, avoiding animals, out of control etc);
- driver intentions prior to collision;
- initial point of impact;
- level of damage; and
- whether the vehicles involved were towing a trailer of some sort.

Crash data is then typically added to a database of some sort. The data contained within crash databases are then analysed in order to establish trends within the data. Additionally the data are used for so called in-depth crash studies, which have been conducted worldwide for a number of years. The ANCIS (Australian National Crash In-Depth Study; Fildes, Logan, Fitzharris, Scully & Burton, 2003) is an example of a major in-depth accident study currently being conducted in Australia. The main aims of the study are to provide a representative sample of vehicle crashes from around Australia for use in improving vehicle crashworthiness and crash involvement (Fildes et al, 2003). The study uses crash data and data elicited from participants admitted to hospital as the result of vehicle crashes. Participants are interviewed and their medical records are examined in order to determine any injuries resulting from the crash. Additionally, photographs of the crash scene and any police reports are examined in order to gather further data and clarify

the crash events. The crash data are then analysed in order to determine crash circumstances and injury causation contributing factors. Upon completion of the analysis, crash cases are then entered into a de-classified crash database.

From an initial analysis of the crash data obtained up to the year 2003 (180 crash cases), Fildes et al (2003) present a summary of the main findings. These included: approximately 75% of all injured occupants were drivers, 17% were front passengers and 10% were in the rear. Unbelted rates were 11% for drivers, 19% front passengers and 31% rear passengers. Children comprised 5% of the sample, older occupants (above 65 yrs) 15%, young adults (25 yrs or less) 23% and the remaining 57% were other adults. Of the vehicles involved, more than half were 4 years old or less. Large cars comprised 40% of the crashed vehicle sample, small cars 39%, 4WDs 8%, sports and luxury vehicles 7%, and medium sized cars 6%. Australian-manufactured vehicles made up two thirds of all crashed vehicles. Two-thirds of the vehicles inspected did not have a driver airbag and three-quarters were without a passenger airbag. Side airbags were not present in more than 90 percent of the crashed vehicles examined. The mean impact severity was 49 km/h and higher in frontal crashes (58 km/h) than side impacts (38 km/h).

Crash severity was typically lower in side impacts. Frontal crashes comprised 48% of the sample, side impacts 36%, rollovers 12%, and rear impacts 4%. The proportion of side impacts in multi-vehicle crashes was much higher in urban areas (51%), while frontals predominated in two-thirds of all rural crashes. Single vehicle crashes were noted in 55% of rural crashes and 45% of urban ones. More than one-third of the crashes occurred in 60 km/h speed zones or less, 35% for 90 or 100 km/h zones, one-quarter in 70 or 80 km/h speed zones, and 2% on 110 km/h freeways. The majority (60%) of the crashes occurred during daylight hours, 28% at night and 12% at either dusk or dawn. A sizeable 84% occurred during fine weather while the rest were experienced in either rain or fog. Intersections were the predominant site for 61% of urban crashes, while mid-block sections accounted for 70% of rural crashes. Only 4% of urban crashes occurred at roundabouts. Almost one-third of the crashes (31%) occurred on curves or bends.

The utility of using in-depth studies to investigate road user error and road transport system latent conditions lies in the ability to access large volumes of data potentially related to error. However, to the authors knowledge, there has yet to be an in-depth study conducted solely for the purpose of identifying and analysing the road user errors and road transport latent conditions involved in accidents. This may be due to the lack of detail in the data from such studies.

## **On the Spot Crash Investigation**

Cuerden, Klunt, Fails & Hill (2003) describe a crash investigation study conducted in the UK that involved over 1,000 on-the-spot crash investigations. Cuerden et al used the On-The-Spot (OTS) methodology, which is based upon the premise that the best crash data is collected immediately post-crash at the scene. Such data collection permits the collection of so-called perishable accident data, including trace marks, contact marks, vehicle resting positions, weather, visibility and traffic conditions (Cuerden et al, 2003). The data collected is then used to reconstruct the crash under analysis. The OTS methodology uses teams of trained accident investigators based at police stations. Using police radio and command and control systems, the investigation team can respond immediately to accidents in their catchment area.

According to Cuerden et al, the following crash-related data is collected at the scene:

- vehicle types, including damage, failures, features fitted and their contribution;
- the highway, including design, features, maintenance and condition;
- the human factors, including factors related to the drivers, riders, passengers, pedestrians involved and also data regarding the training, experience and other road user aspects that might have contributed to the crash; and
- the injuries sustained.

Additional information is also collected where appropriate, including witness statements and casualty details. Questionnaires and interviews are also used to gather data regarding the characteristics of the people involved. Reconstruction is also used when possible to determine the events leading up to and following the crash. An OTS database has been constructed containing the data from all OTS crash investigations. The Interaction coding system has also been developed by the Transport Research Laboratory (TRL) for defining crash causes. It classifies the road users involved according to the following seven sub-categories (Cuerden et al, 2003):

- legal – e.g. disobeying signs, driving whilst under the influence of alcohol or drugs;
- perception – e.g. expecting, looking, planning etc;
- judgement – understanding, deciding, acting;
- loss of vehicle control – e.g. from excessive braking or excessive cornering;
- conflict – e.g. adopted conflicting path with other road user or behaved aggressively towards another road user;
- attention – e.g. driver distraction due to mobile phone usage; and
- impairment – e.g. illness or fatigue.

Each of the road users involved (e.g. active road users) in a particular accident are analysed using the interaction codes described above. Cuerden et al (2003) present the initial results derived from the first phase of the OTS study and present examples of crash analyses using the OTS methodology and the interaction coding system. A total of 1083 crashes were analysed, including fatal (43), serious (120), slight (448), and damage only (472) crashes.

Accident reporting and accident investigation have great potential for collecting error-related information in the road transport domain. If the appropriate procedures were adopted and the correct information were gathered, powerful human error-related data could be collected, including information on system-wide contributory factors and the nature of the errors that led to the accident. However, significant modification to the current road transport accident reporting and investigation procedures would have to be made to ensure that the appropriate error-related information is gathered.

## **4.3 Existing Risk Management Paradigms Within the Road Transport Domain**

### **4.3.1 Introduction**

In the preceding section, an overview of the human error-related research conducted to date in the road transport domain was presented. In conclusion to the literature review, a lack of systems perspective-based human error research within road transport was identified. The next phase of this research involved a review of contemporary risk management paradigms within road transport to determine which of the current paradigms, if any, recognise the role of human error in accident causation in road transport systems. A review of selected approaches highlighted two programs that acknowledge the fallible nature of road users and place an emphasis on the role of human error in road transport accidents. These are the Swedish Vision Zero and the Dutch sustainable road safety approaches. A brief description of each is presented below.

### **4.3.2 Vision Zero**

The Swedish National Road Administration recently launched the Vision Zero paradigm, which comprises a set of principles designed to aid the development of a safer road transport system to prevent fatalities and injuries. Vision Zero is a long-term vision in which eventually nobody will be killed or sustain injury resulting in permanent impairment, within the Swedish road transport system. Vision Zero is a novel approach to road safety and proposes a new set of principles for the design and management of the road transport system (Elvik, 1999). Rather than focusing on enhancing the ability and behaviour of road users, the Vision Zero approach focuses on the design of a road transport system in which road users who comply with regulations will never sustain a fatal or serious injury (Elvik, 1999). The Vision Zero approach recognises the inherent fallible nature of all road users, and that the prevention of all road transport accidents is an unrealistic goal. Rather, Vision Zero aims to control these accidents in a way that ensures that death and injury are prevented. The Vision Zero paradigm has four main components:

1. Human life is not something that can be traded off for road transport system benefits. Human life is the paramount concern;
2. The professional society, politicians and the private sector are responsible for the inherent safety of the road transport system. Citizens should follow the road regulations;
3. The safety of the road transport system should be based on the fallible human, not the perfect human. Designs should allow for human vulnerability; and
4. The driving force for change is the citizen's demand and expectation to stay alive. Road safety should not be an economic issue, but stem from the demands of individual citizens.

The strategic principles of the Vision Zero paradigm include:

- the traffic system must adapt to take better account of the needs, mistakes and vulnerabilities of road users;

- the level of violence that the human body can tolerate without being killed or seriously injured forms the basic parameter in the design of the road transport system; and
- vehicle speed is the most important regulating factor for a safe road traffic system. It should be determined by the technical standards of both roads and vehicle not to exceed the level of violence that the human body can tolerate.

Rather than place the responsibility of safety within the road transport system on system users (e.g. drivers, pedestrians etc), Vision Zero emphasises a sharing of this responsibility between the users of the system and the systems designers. For example, Vision Zero states that (Source: Tingvall & Haworth, 1999):

1. The designers of the system are always ultimately responsible for the design, operation and use of the road transport system and thereby responsible for the level of safety within the entire system.
2. Road users are responsible for following road transport system rules set by the system designers.
3. If road users fail to obey these rules due to lack of knowledge, acceptance or ability, or if injuries occur, the system designers are required to take necessary further steps to counteract people being killed or seriously injured.

Vision Zero is a long-term vision to guide the development of countermeasures and strategies to improve road safety. However, it does not prescribe the content of these potential strategies (Tingvall & Haworth, 1999). Tingvall & Haworth (1999) investigated the applicability of the Vision Zero paradigm to the Victorian road transport system. They proposed a number of potential interventions including reducing travel speeds, investing in infrastructure to control speed where there are potential conflicts between vehicles, creating more forgiving roadsides, restricting speeds to 30Km/h where there are potential vehicle-pedestrian conflicts, defining and developing the interface between vehicles and infrastructure and ensuring that vehicles enforce seat-belt usage, driver sobriety and speed limitation. In conclusion Tingvall & Haworth (1999) suggested that, in the short-term at least, applying Vision Zero principles to the Victorian road transport system would involve large investments into infrastructure related to traffic calming, improved intersections and well designed barriers.

### **4.3.3 The Dutch Sustainable Safer Systems Approach**

The Dutch have also recently adopted a visionary approach to road safety similar to that of Sweden, entitled the 'sustainable road safety' approach. The sustainable road safety approach is based on human capability within the road transport domain, and assumes that humans are fallible and make mistakes due to the heavy demands that are placed upon them within the road transport system. The underlying principle of the sustainable road safety approach is that the road transport system should be adapted to the capabilities of humans in a way that allows them to behave safely. The approach proposes that sustainably safe systems should be based upon the following three key safety principles (Oxley, Corben, Koppel, Fildes, Jacques, Simmons & Johnston, 2004):

1. Functionality: the traffic will be distributed over the road network.

2. Homogeneity: there will be small speed and mass differences between transport modes that can collide.
3. Recognition: traffic situations are, to a great extent, predictable, so that road users know what behaviour is expected of them and of other road users.

Further, the sustainable road safety approach emphasises the need for:

- an infrastructure that is adapted to the limitations of human capacity through proper road design;
- vehicles fitted with ways to simplify the task of drivers and constructed to protect the vulnerable human as effectively as possible, and
- a road user who is adequately educated, informed and, where necessary, controlled.

These three principles are further divided into the following 12 aims:

- the realisation of largest possible contiguous residential areas;
- ensure that only a minimal portion of the trip is taken along unsafe roads;
- make trips as short as possible;
- use the shortest and safest route possible;
- avoid searching for destinations;
- make road categories recognisable;
- limit and make uniform the number of traffic solutions;
- avoid conflicts with oncoming traffic;
- avoid conflicts with traffic crossing the road that you are on;
- separate vehicle types;
- reduce speed at potential points of conflict; and
- avoid obstacles along the carriageway.

In order to achieve such parameters, the sustainable safety approach emphasises a reduction in alcohol use, an increase in seatbelt use, speed management, separation of cyclists and vehicles, improvement of hazardous locations, addressing issues regarding heavy vehicles, and providing a self-explaining network infrastructure (Oxley et al, 2004). Recent statistics suggest that the adoption of the sustainable safe system principles has led to a 17 percent reduction in fatalities and a 22 percent reduction in personal injury to vulnerable road users (OECD, 1998; Breen, 2002; cited in Oxley et al, 2004).

The aspects of the Vision Zero and Sustainably Safer Systems approaches most relevant to this research are that they recognise the fallible nature of the actors (e.g. drivers, cyclists, pedestrians) who perform activity within the road transport system, and that they strive for crash or error tolerance within their respective road transport systems. The acceptance that road users will make errors within the road transport system represents a move away from the traditional perspective on road transport system safety that focussed upon the enhancement of road user skills and behaviour and the eradication of road user error and represents the first step towards error tolerant systems, removing the emphasis from the complete eradication of error within a system,



to the tolerance of error within a system. The responsibility for safety is no longer placed solely on the users of the system, it becomes a shared endeavour between the designers and the users of the system. For example, Vision Zero accepts that road accidents cannot be completely eradicated, and therefore attempts to promote crash or accident tolerance within the road transport system. Similarly, the sustainably safe systems approach recognises that road users make errors, and focuses upon adapting the road system infrastructure to the capabilities of the road users. An error tolerant road system should accept that road user errors are a permanent feature within the road transport system, and take measures to increase the road transport systems tolerance of road user errors.

#### **4.4 The Current Approach to Road Transport Risk Management in Australia**

Unlike the visionary approaches currently adopted in Sweden and Holland (e.g. Swedish Vision Zero and Dutch Sustainably Safe Systems approaches) the current national road safety strategy in Australia is target based, and aims to significantly reduce death and injury on Australian roads. Specifically, the current Australian road safety approach has the target of achieving by 2010 a 40% reduction in the number of fatalities per 100,000 population recorded in 1999 (9.3/100,000; Australian Transport Council, 2005). The National road safety strategy aims to achieve this through the continuation of effective measures, the enhancement and/or wider implementation of measures with further potential, the introduction of new measures and through the pursuit of the following strategic objectives (Australian Transport Council, 2005):

- improve road user behaviour;
- improve the safety of roads;
- improve vehicle compatibility and occupant protection;
- use new technology to reduce human error;
- improve equity among road users;
- improve trauma, medical and retrieval services;
- improve safety policy and programs through research of safety outcomes; and
- encourage alternatives to motor vehicle use.

The strategic objectives outlined above mainly focus on enhancing road user behaviour and improving the safety of road transport system infrastructure. Particularly pertinent is the focus on improving road user behaviour and reducing human error through the use of new technology. This person-based approach is different from the Swedish Vision Zero and Dutch Sustainably Safe Systems approaches in that it attempts to enhance road user behaviour and reduce or eradicate human error. The Vision Zero and Sustainable Safe Systems approaches take a systems perspective approach, in that they accept that fallible road users will always make errors and instead aim to promote error tolerance throughout the road system. More recently however, the Australian Transport Council presented a National Road Safety Action plan for 2005 and 2006 which included the Safe System concept, a new framework for enhancing road safety in Australia. The Safe System Framework, represents a significant shift towards the error tolerance-related

principles adopted by the Vision Zero and Dutch Sustainably Safe Systems approaches. The Safe system framework is presented in Figure 4.4 (Australian Transport Council, 2005). The Safe system concept aims to produce safer road infrastructure, safer speeds and safer vehicles within the Australian road transport domain and emphasises that the foundation for this is safer road users. According to the Australian Transport Council, safer road users are alert and compliant with the rules that reflect design standards for safety in the system and allow for some degree of human error, and safer road user behaviour depends on compliance with rules, admittance to the system, and support for driving and travelling. On the basis of the safe system concept, the Australian Transport Council proposed a National Road Safety Action plan for 2005 and 2006 comprising initiatives over the following five areas:

- safer roads and roadsides;
- safer speeds;
- safer vehicles;
- safer road users; and
- other supporting measures.

Within these areas, a marked recognition of road user error is evident. For example, within the area of safer roads and roadsides, one of the proposed solutions to high casualty rates is to make the road infrastructure more forgiving of human error.

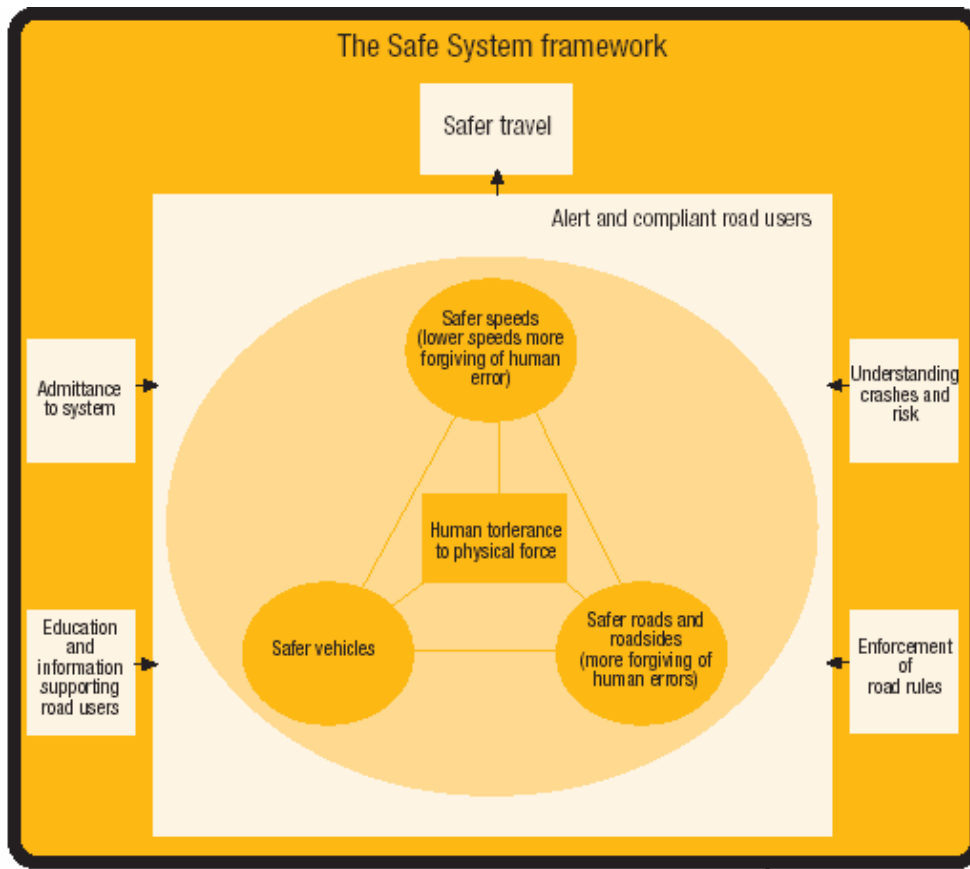


Figure 4.4. Safe System Framework (Australian Transport Council, 2005).

The safe system framework represents a significant shift toward a systems perspective approach to human error within the road transport domain. The concept of error tolerance within the Australian road transport system is therefore gaining credence. This is encouraging, and it is our opinion that this approach is worthwhile. However, as highlighted previously, such an approach requires that error related data is collected throughout the Australian road transport system. Increased tolerance to error within the road transport system can only be achieved through a comprehensive understanding of the types of errors which occur, their consequences, and the contributory factors involved. Such information is currently not sufficiently available in the Australian road transport domain.

#### **4.5 Error Management Techniques Currently Employed Within the Australian Road Transport System**

The results of the literature review indicate that currently only limited attention is given to error management within the Australian road transport system. It is also concluded that the means with which to enhance our knowledge in this area are currently limited. That is, the methods used in other domains to gather and analyse data to better understand error are currently not employed or are not available within the road transport system. Of the error management and error data collection approaches described previously, only accident reporting and investigation is, or has been, employed within the Australian road transport system, and this does not have a specific focus on error. Additionally, accident investigation and analysis is not compulsory and is typically only performed during in-depth accident studies. Training is used within the road transport system, however, this does not currently focus on error or on strategies for managing errors as they arise.

There are currently no incident reporting systems available to road users, and a large proportion of crashes and error related incidents go unreported. Of those that are reported, a large proportion are not adequately investigated and of those accidents that are investigated, the limited nature of the data collected means that comprehensive error analysis is extremely difficult or even impossible. To the authors' knowledge, HEI approaches have also not been employed during the design of road transport systems, infrastructure and vehicles, nor have they been used for the prediction of road user errors in existing road transport systems. It is therefore reasonable to conclude that, as a result of the current lack of error management procedures in the Australian road transport system, our knowledge of the system's latent failures, and road user error and its associated causes and consequences is somewhat limited. Additionally, much error-related data is unobtainable because there is no way with which to collect it. This means that we currently do not properly understand the nature of the system-wide latent failures that exist, their role in error occurrence, and the nature and consequence of the errors made by different road users. In consequence, a framework for error tolerance within the Australian road transport domain needs to provide both the techniques required for the *collection* of latent failure and error-related data, and also the techniques required for the *analysis* of error related data. Error tolerance strategies can then be proposed on the basis of the error data analysed.

## 4.6 Summary

The literature review indicates that, in comparison with other domains in which human error has been identified as a problem, there has been only a limited amount of human error-related research conducted in road transport. The literature review also indicates that the majority of human error-related research conducted to date in road transport has been conducted from a person-based perspective. That is, most of the research described above has attempted to identify and classify the nature and frequency of the errors made by drivers and also the person-based causal factors that contribute to these errors. For example, much of the research has involved the subjective DBQ developed by Reason et al (1990) to identify different classes of driver error within different driver populations. Moreover, research into the different types of errors made by elderly drivers also represents a large portion of the research reported in the literature. This is not to say that the systems perspective approach has been totally neglected, although it has received only limited attention to date. Systems perspective-based research in the road transport domain has increased markedly in recent years and it is apparent that the research community is beginning to adopt this perspective.

It is significant that there have been no attempts to use mass accident and incident data to determine the different types of errors made by road users and their associated causes. Consequently, there is currently only limited information on the different errors made by road users and the contribution of system-wide latent conditions to error occurrence. It is the opinion of the authors that this represents a significant gap in our knowledge. As alluded to previously, it was concluded that the understanding and management of error in complex sociotechnical systems requires the provision of structured methods that can be used for the collection of pertinent error-related data. There is currently a lack of approaches developed specifically for use in the road transport domain. Currently, data collection and analysis is achieved through the use of standard accident reporting (e.g. Police) and investigation (e.g. in-depth crash studies), which typically do not consider error-related information. The collection of appropriate error-related information is currently lacking within the road transport domain. It is the opinion of the authors that the current understanding of error within the road transport domain is limited, and that there is scope for much further research into the construct, particularly with regards to systems perspective-related research and the development of structured error-related data collection techniques. It is also recommended that appropriate techniques for collecting error-related information within the road transport domain should be investigated and developed.

From the review of existing road transport risk management paradigms, it was concluded that the Swedish Vision Zero and Dutch Sustainable Safer Systems approaches currently acknowledge the fallibility of road users and emphasise error tolerance within their respective road systems. The current Australian National road safety plan has the target of achieving a 40% reduction in the number of fatalities per 100,000 population by 2010 (Australian Transport Council, 2005). The National road safety strategy aims to achieve this through the continuation of effective measures, the enhancement and/or wider implementation of measures with further potential, the introduction of new measures and through the pursuit of strategic objectives including the improvement of road user behaviour, road safety, vehicle compatibility and occupant protection, equity among road users, medical services, and the reduction of human error. This person-based approach is different from the Swedish Vision Zero and Dutch Sustainably Safe Systems approaches in that it attempts to enhance road user behaviour and reduce or eradicate human error. More recently however, the Australian Transport Council presented a National Road Safety

Action plan for 2005 and 2006 which included the Safe System concept, a new framework for enhancing road safety in Australia. The Safe System Framework represents a significant shift towards the error tolerance related principles adopted by the Vision Zero and Dutch Sustainably Safe Systems approaches.

There is currently only limited attention given to error management within the Australian road transport system. Our knowledge of road transport system latent conditions, road user error, and its associated causes and consequences is limited. Additionally, a large amount of error-related data is currently unobtainable due to a lack of the means with which to collect such data (e.g. error-focused accident and incident reporting). We currently do not, and cannot, fully understand the nature of the system-wide latent conditions that exist within the road transport system, their role in error occurrence and also the nature and consequence of the errors made by different road users. It was also concluded that a framework for error tolerance within the Australian road transport domain should provide both the techniques required for the collection of latent conditions and error-related data, the techniques required for the analysis of error-related data, and also the techniques required to manage the errors and latent conditions identified.



## Chapter 5 Conclusions

### 5.1 Summary of findings

The main aims of this report were to review the literature on human error-related research in complex, sociotechnical systems (including road transport domain), and review the different human error-related risk management approaches employed in domains other than road transport.

The first phase of this research involved a review of the human error-related research conducted to date in domains other than the road transport domain. The literature review indicates that a number of different classification schemes, models, theories and taxonomies of human error have been proposed, all of which can be broadly classified as either person-based or systems-based human error approaches. Person-based approaches (also known as the ‘old-view’ on human error) view errors as the result of psychological factors or aberrant mental processes within an individual, such as forgetfulness, inattention, poor motivation, negligence and recklessness. Such approaches focus on the tendency that operators have to make errors at the so-called ‘sharp-end’ of system operation, and view error as the major cause of accidents and incidents in complex, dynamic domains. Person approach-based research typically attempts to identify the nature and frequency of the errors made by actors within complex systems, the ultimate aim being to propose strategies and countermeasures designed to prevent future error occurrence. When using the person approach, human error is treated as the primary cause of most accidents: the systems in which people work are assumed to be safe; human unreliability is seen as the main threat to system safety; and safety progress is achieved by protecting systems from human unreliability through automation, training, discipline, selection and proceduralisation (Dekker, 2000). Examples of person-based models of human error include the GEMS proposed by Reason (1990), and the model of human malfunction proposed by Rasmussen (1982). The most commonly referred to error classification scheme is the slips and lapses, mistakes and violations classification proposed by Reason (1990).

It was concluded that the majority of initial or early error-related research conducted within complex, sociotechnical systems can be categorised as person-based error research. However, the literature also indicates that the focus of human error-related research has shifted in recent years, and so called systems-approaches (also known as the ‘new-view’ on human error) are becoming dominant within safety-critical systems. Systems perspective approaches consider the combined role of latent conditions (e.g. inadequate equipment, poor interface design, and inappropriate or inadequate training) residing throughout the different organisational levels of a particular system and the errors made by front-line operators in accident causation. It is now widely accepted that human error in complex systems is a consequence of the various latent conditions that exist throughout the system, rather than the primary cause of accidents and incidents. The most prominent systems-approach to error in complex, sociotechnical systems is the swiss cheese mode of error and accident causation proposed by Reason (1990). It was concluded that the systems perspective approach, in particular the systems perspective model proposed by Reason, is the most appropriate approach for error management in complex, sociotechnical systems.

The next phase of the research involved reviewing the different human error management practices employed in domains other than road transport. A review of the literature associated with risk and human error management was conducted. The literature review indicates that error management programs have been employed in a number of different domains, including civil aviation, medicine, nuclear power, oil exploration and production, rail and air traffic control. The main purpose of such programs is to better understand the nature of errors and latent conditions within systems, identify and develop countermeasures, procedures and strategies that might lead to the mitigation of these errors and latent conditions, and promote error tolerance within systems. A plethora of different techniques and methods that are used as part of error management programs in complex, socotechnical systems were identified. These include accident analysis and investigation techniques, incident and near-miss reporting systems, HEI and HRA, and error management training. A brief summary of the error management approaches reviewed is presented below.

- Accident investigation and analysis. Retrospective accident analysis and investigation involves the use of structured techniques to identify the human and system contributions to accidents. There are various accident analysis techniques available, such as HFACS, ICAMS, fault tree analysis, AcciMaps, and TRACEr. It was concluded that accident analysis is attractive for a number of reasons, including that it exposes investigators to the entire sequence of events, including triggering conditions, and outcome, that it permits the identification of the human and systemic causal factors involved in a particular accident and also the identification of system failures or latent conditions, such as bad design, inadequate training, inadequate equipment and poor management, and aids the development of countermeasures designed to prevent similar accidents occurring in the future. It was also concluded, however, that accident analysis approaches are beset by a number of problems, including the apportioning of blame to individuals, and the various problems associated with hindsight.
- Incident reporting systems. Incident reporting systems are used to collect pertinent information on critical incidents (or near misses), error, safety compromising incidents and safety concerns within complex, dynamic systems. The literature indicates that incident reporting systems are now common in most safety-critical domains, including the aviation domain (e.g. ASRS), the healthcare domain (e.g. MedWatch) and nuclear power domains (e.g. MARS). It was concluded that the utility of such systems lies in their ability to generate large amounts of incident or near-miss data that would otherwise go un-noticed or unreported. Incident reporting systems work on the premise that these near-misses are indicators of accidents waiting to happen, and so preventative measures can be taken before accidents occur. The data obtained is useful as it can be used to identify the types of errors made, the causes of the errors made, and also recovery strategies for the errors made in a particular system. It was also concluded that there are a number of disadvantages that may affect the data collected. These include reluctance by system personnel to report incidents for a number of reasons, a perceived worthlessness and skepticism of such schemes, problems relating to the accuracy of incident descriptions, the high cost associated with running such schemes, and the various biases that incident report data are subject to.
- Human Error Identification. HEI techniques are used to predict potential human or operator error in complex, dynamic systems. A number of different HEI approaches were identified, including taxonomy-based techniques, error identifier techniques, error quantification techniques, cognitive modeling techniques and cognitive simulation techniques. The literature



also indicates that HEI techniques have previously been employed in a number of different domains, including the nuclear power and petro-chemical processing industries (Kirwan, 1996), air traffic control (Shorrock & Kirwan, 2002), aviation (Marshall et al, 2003), naval operations, military systems, space operations (Nelson et al, 1998), medicine and public technology (Baber & Stanton, 1996). The utility of HEI techniques lies in their ability to identify potential errors before they occur, allowing pro-active remedial measures to be taken. This also allows them to be applied early in the design process, before an operational system actually exists. It was also concluded, however, that HEI techniques suffer from a number of problems, including issues regarding the reliability and validity of such techniques. For example, different analysts, with different experience, may make different error predictions for the same task (inter-analyst reliability). Similarly, the same analyst may make different judgements on different occasions (intra-analyst reliability).

- **Training.** Training is also used as a part of error management in complex, dynamic systems. The literature review indicates that, traditionally, retraining operators was the most common response to continued error occurrence in complex sociotechnical systems and novel training interventions and retraining were used to try and reduce error occurrence in such systems. As a result of the literature review, the concept of error management training was identified. Error management training is a form of crew resource management (CRM) training that attempts to provide operators with the skills (technical and non-technical) to detect and manage errors as and when they arise.
- **Error databases.** The culmination of error-related data collection in complex sociotechnical systems is typically the development of an error database. Error databases are used for a number of purposes, including for in-depth studies, the identification of different error trends, quantitative error analysis and to inform the development of error countermeasures.
- **Traditional data collection techniques.** A number of traditional data collection techniques have also been used in the past to collect error-related data in complex, sociotechnical systems, including observational study, interviews and questionnaires. Such approaches are attractive as they offer a simple means of collecting error-related data, are typically inexpensive and can be used to collect large volumes of error data.
- **Specific error management techniques.** The literature indicates that a number of approaches have also been developed specifically for error management purposes in safety-critical domains e.g. TRIPOD Delta, REVIEW and MESH. Such approaches work by identifying significant error causing conditions and informing the development of countermeasures designed to reduce error causing or latent conditions.
- **General error management techniques.** The literature review also considered other, more general, approaches to error management within complex, sociotechnical systems, including procedures, checklists, system redesign, awareness campaigns and the introduction of novel technology and artifacts.

It was also concluded that the following key aspects of error management should be considered when designing and implementing error management programs:

- the effectiveness of error management programs appears to be entirely dependent on the collection and analysis of accurate data on the nature of, and contributory factors associated with, errors and latent failures within a system. The error data collected is key to identifying

and understanding the errors and causal factors involved, and also to the development of strategies and countermeasures designed to manage, eradicate or tolerate error occurrence;

- regardless of experience, skill-level, technological support, training and other factors, errors are consistently, and always will be, made by operators within complex systems;
- error management should recognise that the errors made by operators within the system are a consequence of latent conditions residing throughout the system; and
- error management should recognise that accident causation in complex, dynamic systems typically involves a combination of latent conditions residing within the system and also errors committed by operators performing activity within the system.

The literature review also yielded a number of general conclusions regarding error management in safety-critical domains:

- error management programs have been implemented in a number of different domains, including civil aviation, medicine, nuclear power and rail;
- error management programs are used to better understand the nature of errors and latent failures within systems, identify and develop countermeasures, procedures and behaviours that might lead to the mitigation of these errors and latent failures, and promote error tolerance within systems;
- successful error management programs are based on an acceptance that humans make errors, and focus on the development of error tolerance within systems in addition to the eradication of error;
- contemporary error management programs adopt a systems, rather than a person approach to error within complex systems; they consider the combined role of latent failures and active errors in accident causation;
- there are numerous error management-related approaches available, including incident reporting systems (e.g. ASRS), accident investigation tools (e.g. HFACS), human error identification techniques (e.g. SHERPA), and error management training programs (e.g. CRM);
- error management programs normally employ a mixture of the error management-related techniques available, and the techniques used are dependent upon the domain in which the program is implemented;
- error management programs depend on the collection of accurate data on the nature of, and contributory causes associated with, errors in complex, dynamic systems; and
- there have been only limited attempts to implement error management programs in the road transport domain worldwide.

Next, a review of the human error-related research conducted to date within the road transport domain was conducted. The literature review indicates that, compared to other domains in which human error has been identified as a major problem, there has been only a limited amount of human error-related research in road transport. Using the person and systems approach described previously, the research conducted to date in road transport was categorised into person-related and systems-related research. The majority has been conducted from a person-based perspective. That is, most of the published research has attempted to identify and classify the nature and

frequency of the errors made by drivers and the person-based causal factors that contributed to these errors. For example, a large portion of the research conducted to date has involved the use of the DBQ developed by Reason, et al (1990). This is not to say that the systems perspective approach to human error has been totally neglected. Systems perspective-based research in the road transport domain has increased markedly in recent years. For example, Wierwille, Hanowski, Hankey, Kieliszewski, Lee, Medina, Keisler & Dingus (2002) describe a comprehensive study that was conducted at the Virginia Tech Transportation Institute in order to investigate the nature and causes of driver errors and their role in crash causation, to develop driver error taxonomies and also to develop recommendations for improvements in traffic control devices, roadway delineations and accident reporting forms. Amongst other things, a crash-contributing factors taxonomy was developed. According to the taxonomy, there are four different groups of factors that contribute to task performance problems that occur during crashes: inadequate knowledge, training and skill; impairment; wilful behaviour; and infrastructure and environment. According to Wierwille et al, these factors combine in different ways to influence driver task performance, which in some cases may lead to incidents and accidents.

Significantly, of the human error-related research conducted to date in the road transport domain, it was concluded that there have been no attempts to use mass accident and incident data to determine the different types of errors made by road users and their associated causes. Consequently, there is only limited information available regarding the different errors made by road users and the contribution of system wide latent conditions to error occurrence. It is the opinion of the authors that this represents a significant gap in our knowledge of road user error in road transport. As alluded to previously, the understanding and management of error in complex, dynamic systems requires the provision of structured methods that can be used for the collection of pertinent error-related data. There is a lack of such approaches developed specifically for use in road transport. Currently, data collection and analysis is achieved through the use of standard accident reporting (e.g. police) and investigation (e.g. in-depth crash studies), which typically do not consider error-related information. There is scope for much further research into the construct, particularly with regards to systems perspective-related research and the development of structured error-related data collection techniques.

To conclude, it is our opinion that this research has demonstrated that there is currently a distinct lack of knowledge regarding human error and latent conditions in the Australian road transport system. The literature indicates that there has been only relatively little human error-related research conducted within road transport. In addition to this, the review of error management approaches also leads us to conclude that the concept of error management has only previously received limited attention in road transport, and therefore that there is currently a lack of the means with which to collect the error-related data required to enhance our current understanding of road user error and latent conditions within the Australian road transport domain. Of the error management approaches that have been used previously in other complex sociotechnical systems, it was concluded that a number could potentially be used within the Australian road transport system as part of an error management program. These applicable error management-related techniques include error and latent condition classification schemes, specific error management techniques, accident investigation and analysis, incident reporting, human error identification, error management training and error databases.

## 5.2 Recommendations for Further Research

In the course of conducting the research reported here, it became apparent to the authors that there is great scope for further research on the construct of human error within road transport, particularly with regards to the collection and analysis of human error-related data and the development and application of error management approaches. The authors propose that several areas of further research be investigated:

- Conduct of human error study within the Australian road transport system. To investigate human error and latent conditions in the Australian road transport domain, it is proposed that a pilot study be designed to collect data on errors and latent conditions at intersections. The design and conduct of a proof-of-concept pilot study forms the next phase of this research, and it is proposed that a number of the methods described in this report be used to collect and analyse specific data on latent conditions at selected intersection sites.
- Development of a model of road user error. A model of road user error is yet to be developed for the Australian road transport system. The authors recommend that a model of road user error be developed on the basis of the research conducted so far and the results of the proposed human error pilot study.
- Development of road user error and latent condition classification schemes. Road user error taxonomies and road transport system latent condition classification schemes have not yet been developed for the Australian road transport system. The authors recommend that classification schemes containing taxonomies of road user error and of the latent conditions currently residing at intersections and throughout the Australian road transport system be developed on the basis of previous road transport-related human error research conducted in other jurisdictions. It is recommended that the prototype classification schemes be used during the proposed pilot study to classify the error-related data that is collected. The classification schemes will also be refined and validated as a result of the proposed pilot study.
- Investigation, development and implementation of novel error data collection procedures within the Australian road transport system. The current lack of appropriate error data collection procedures within the Australian road transport system was discussed in this report. The authors recommend that the development and implementation of appropriate data collection procedures be investigated within the Australian road transport system. Potential data collection procedures include observational study, site-surveillance, accident reporting and investigation, incident reporting and analysis of insurance data.
- Investigation, development and implementation of novel error management approaches within the Australian road transport system. The current lack of the use of error management techniques within the Australian road transport system was discussed in this report. The authors recommend that the development and implementation of appropriate error management techniques be investigated within the Australian road transport system. Potential error management strategies include the use of structured error management techniques (similar to the REVIEW and TRIPOD DELTA approaches described above), error management training, human error identification, and advertising campaigns.

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