



**MONASH** University  
Accident Research Centre

**HUMAN ERROR AND ROAD TRANSPORT:  
PHASE TWO – A FRAMEWORK FOR AN ERROR  
TOLERANT ROAD TRANSPORT SYSTEM**



**HUMAN ERROR AND ROAD TRANSPORT:  
PHASE TWO – A FRAMEWORK FOR AN  
ERROR TOLERANT ROAD  
TRANSPORT SYSTEM**

by

Paul Salmon

Michael Regan

Ian Johnston

January 2006

Report No. 257



# Monash University Accident Research Centre Report Documentation Page

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Report No.	Date	ISBN	Pages
257	January 2006	0732623278	77

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**Title and sub-title:**

Human Error and Road Transport: Phase Two – A framework for an error tolerant road transport system

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**Author(s):**

Salmon, P. M.; Regan, M. A.; Johnston, I.

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**Sponsoring Organisation(s):**

This project was funded through the Australian Transport Safety Bureau (ATSB) and the Centre's Baseline Research Program for which grants have been received from:

Department of Justice  
Transport Accident Commission

Roads Corporation (VicRoads)

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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. This report represents the second 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. Based on a review of the human error-related literature, a review of the human error-related research conducted to date and of the error management techniques that have previously been employed in other complex socio-technical systems, a conceptual framework for an error tolerant Australian road transport system was proposed. The proposed framework contains appropriate methods for the collection and analysis of human error-related data within the Australian road transport system, and also a number of error management approaches and strategies that could potentially be used to reduce or manage road user error and the conditions that lead to it. It is proposed that the framework for error tolerance be used during the next phase of this research program to inform the design of a pilot study of road user error and error-causing conditions at intersections in Victoria.

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**Key Words:**

Human Error, Road Safety Error, Transport Safety

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Monash University Accident Research Centre,  
Wellington Road, Clayton, Victoria, 3800, Australia.  
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363

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# Preface

## Project Manager

- Dr Michael Regan

## Research Team

(in alphabetical order)

- Prof Ian Johnston
- Dr Michael Regan
- Mr Paul Salmon

## Correspondence

Please direct all correspondence to:

Dr Michael Regan

Monash University Accident Research Centre

Building 70

MONASH UNIVERSITY VIC 3800

Telephone: (03) 9905 1838

Facsimile: (03) 9905 4363

E-mail: [michael.regan@muarc.monash.edu.au](mailto:michael.regan@muarc.monash.edu.au)

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## Glossary

AcciMaps	Accident Maps
ACT	Australian Capital Territory
ANCIS	Australian National Crash In-Depth Study
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATSB	Australian Transport Safety Bureau
CARS	Confidential Accident Reporting System
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
HEI	Human Error Identification
HET	Human Error Template
HFACS	Human Factors Analysis and Classification System
HTA	Hierarchical Task Analysis
ICAM	Incident Cause Analysis Method
ITS	Intelligent Transport Systems
MEDA	Maintenance Error Decision Aid
MUARC	Monash University Accident Research Centre
PEM	Psychological Error Mechanism
REDA	Ramp Error Decision Aid
SHERPA	Systematic Human Error Reduction and Prediction Approach
SME	Subject Matter Expert
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, being consistently 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 use of traditional error management programs within the road transport domain has been only minimal, and as a result 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 report represents the second phase of the research program, the aim of which was to develop a conceptual framework designed to promote error tolerance at intersections and in the Australian road transport system as a whole. This phase of the research was partitioned into three stages: the development of a conceptual framework for promoting error tolerance within the Australian road transport system; an investigation of potential error management applications within road transport; and the conduct of a human error workshop designed to gather feedback on, and refine, the proposed error tolerance framework.

## Toward a Framework for Error Tolerant Intersections and an Error Tolerant Australian Road Transport System

The literature review conducted during the first phase of this research (Salmon, Regan & Johnston, 2005) indicated that the key aspects of error management within complex, sociotechnical systems include the recognition of the fallible nature of humans and the inevitability of error occurrence, and the enhancement of error tolerance throughout the system. Rather than attempt solely to enhance system safety through the eradication of errors, systems should also be made safer by increasing their tolerance of errors. It was also concluded that despite road safety professionals' best efforts, safety interventions, strategies, new technologies and countermeasures will never completely eradicate road user error. Drivers, pedestrians, and other road users will continue to make errors for as long as the road system exists. It was therefore concluded that, rather than focusing entirely upon removing road user error through increased training, awareness campaigns and enhanced technology, effective error management in road transport should, as a complimentary aim, focus on increasing the capacity of the road transport system to tolerate error.

On the basis of the work conducted during Phase 1 of this research program, a conceptual framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole was developed. This involved identifying potential

human error-related applications from other domains that could be used in the road transport domain as part of an error management program. The proposed framework contains both the methods with which to collect and analyse error-related data and also a number of error management approaches designed to reduce, eradicate or manage road user error and its contributory conditions. It is recommended that targeted error management strategies are then developed on the basis of the collection and analysis of human error-related data. The framework was proposed both as a way of increasing our understanding of road user error, and for enhancing error tolerance at intersections and throughout the road transport system. The novelty of the framework is that it attempts to make error-data collection, error management and error tolerance strategy development standard components of the overall working system, rather than part of reactive error-related studies. The proposed framework contains the following human error-related applications:

- application of existing human error theory in the road transport domain;
- collection of error-related data at specific road sites;
- development of road user error and latent condition classification schemes;
- development of a human factors oriented road transport accident reporting tool;
- development of a road transport incident or near-miss reporting system;
- development of road user error and latent condition databases;
- development of a valid human error identification technique for the road transport domain;
- development of a road transport-specific error management technique;
- development of error tolerance strategies (e.g. infrastructure and in-car technology design) and policies (e.g. legislation and advertising campaigns) designed to increase error tolerance and/or mitigate error and its consequences within the road transport domain; and
- development of error management driver training interventions.

It is the opinion of the authors that the implementation of the proposed framework could form the first steps in the development of error-tolerant intersections and an error-tolerant road transport system in Australia, and could in turn enhance road user behaviour and safety considerably. It is also intended that the methods required for the error pilot study that is to be designed and conducted during the next phases of this research program are extracted from the framework.

## **Investigating potential road transport human error applications**

To demonstrate the potential application of the framework, each component application area was investigated with regard to its potential application within the Australian road transport system. Firstly, the systems perspective approach to human error and accident causation proposed by Reason (1990) was related to the Australian road transport system, and was then used to analyse a series of road traffic crash scenarios. The results indicated that the systems perspective is a useful approach for analysing incidents and accidents in the road transport domain. Additionally, it was concluded that the development of a road transport-specific error accident investigation approach, similar to the HFACS accident investigation approach that is used within the aviation domain, be investigated further.

Secondly, the concept of error classification within the road transport domain was discussed. It was recommended that road user error and road transport system latent condition classification schemes be developed, based on information derived from several sources: existing error classification schemes and error taxonomies (e.g. HFACS, DREAM); accident reports; information derived from the analysis of road traffic accidents (using data from accident databases); information collected from a road transport incident or near-miss reporting system; information collected from on-site and in-car observational studies and information derived from road user interviews and questionnaires. To investigate error and latent condition classification further, a model of road user error was developed along with prototype road user error and error contributing conditions classification schemes. It is recommended that these are used for the conduct of the error pilot study during the next phases of this research program.

Thirdly, the concept of accident reporting and investigation in the road transport domain was investigated. It was found that the current approach to accident reporting in Victoria is inadequate for error and latent condition analysis purposes. In particular, the level of detail contained and type of information collected inhibit the analysis of the errors and latent conditions involved in accidents. It was recommended that a novel approach to accident reporting and analysis be developed.

Fourthly, the use of incident or near-miss reporting schemes within the road transport domain was investigated. The potential utility of such an approach within the road transport domain led the authors to conclude that the development and application of a road transport incident reporting system be investigated further.

Fifthly, the use of observational study, questionnaires and road user interviews for the collection of error-related data was discussed. These traditional data collection procedures offer a viable means for collecting human error-related data within the road transport domain. However, a number of associated disadvantages were also identified that could significantly impact the quality of the data collected. These include a lack of experimental control, a limit to the information that can be derived from such data (for example, it may be impossible to determine why errors occurred and also the latent conditions involved in their occurrence) and also the high cost and time involved in analysing the data collected.

Sixthly, the concept of Human Error Identification (HEI) in the road transport domain was investigated. In order to investigate the potential application of HEI techniques within the road transport domain, an exploratory Systematic Human Error Reduction and Prediction Approach (SHERPA) analysis of an intersection scenario was conducted. The results of the exploratory analysis indicated that error prediction within the road transport domain is an appropriate concept to pursue. It was recommended that a road transport-specific HEI technique be developed.

Finally, the application of error management training within the road transport domain was discussed. It was recommended that the concept of error management training within the road transport domain be investigated further.

Potential error tolerance strategies that might arise from the human error-related applications described above were identified. The following were proposed:

- training;
- error management technique;
- road infrastructure design;

- vehicle design;
- policy, regulations and legislation; and
- advertising campaigns.

## **Human Error Workshop**

To gather feedback on, and to refine the proposed error tolerance framework, a workshop was convened by MUARC. The workshop involved a number of project stakeholders and also Subject Matter Experts (SMEs) from the road transport and other relevant domains in which error management approaches have previously been implemented. Workshop participants were given a presentation detailing the findings from the first phase of the research program and an outline of a proposed framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole. Several key conclusions derived from the workshop included:

- due to the size and complexity of the road transport system in Australia, it may be more useful to focus the finite project resources initially on error at intersections only rather than on error in the road transport system as a whole. This would allow the framework to be tested and refined in a more controllable and manageable environment before it is implemented system wide;
- the methodology that is employed to collect the error data is particularly important with regard to the quality of the data that is gathered and to the subsequent error management strategies that are developed. Therefore the data collection procedure employed needs to be clearly defined prior to the conduct of an error study;
- the road transport system is an ‘open’ system with lots of variation in terms of behaviour and vehicle condition, standard and capability. Historically, error management programs have been implemented in ‘closed’ systems. However, the open nature of the road transport system should not inhibit the use of error management programs or the conduct of further error-related research;
- there are a number of reasons why error management has not been employed within road transport to date. These include the open nature of the road transport system, the previous focus on controlling violations rather than errors, and also the difficulties associated with collecting error data within the road transport system;
- it may be useful to use a modified accident reporting form to allow the police to collect, initially for a trial period, error-related data during accident reporting; and
- incident reporting may be too difficult to implement within the road transport system.

## **Conclusions**

The research conducted during the previous phase of this research program demonstrated, among other things, that there is currently a lack of knowledge regarding human error and latent conditions in the Australian road transport system. Further, the means (e.g. via error data collection techniques) with which to collect the error-related data required to enhance our understanding of error and latent conditions is lacking. In response to this, a conceptual

framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole was proposed. The framework comprises a series of methods for the collection and analysis of error-related data, and a number of potential error tolerance strategies. Each component of the framework was investigated with regard to its potential application within road transport. In conclusion, it is our opinion that these exploratory applications demonstrate that there is potential for applying the framework within the Australian road transport system, and that the development and application of error management programs within road transport is a viable concept to pursue. It is recommended that the framework be used to inform the development of the methodology for the error pilot study that is to be designed and conducted during the next phase of this research program.

### **Recommendations for Further Research**

During the conduct of this phase of the research, 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 design and conduct of a pilot study designed to collect data on errors and latent conditions at intersections;
- re-iteration and validation of the prototype road user error and latent condition classification schemes;
- 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 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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## Acknowledgements

First, and foremost, the authors would like to thank the MUARC Baseline Road Safety Research Program and the Australian Transport Safety Bureau for sponsoring this project and for their interest in this line of research. In particular, we would like to thank Mr David Healy (Transport Accident Commission), Mrs Janet Anderson (formerly MUARC), Mr Chris Brooks (ATSB) and Mr Kym Bills (ATSB) for their respective roles in establishing funding for this research program.

We also wish to thank the following people for taking part in a human error workshop that was conducted as part of this research: Prof Tom Triggs, Dr Narelle Haworth, Prof Brian Fildes, (MUARC), Dr Marcus Matthews (ATSB), Dr Antonietta Cavallo (VicRoads), Dr Nial Finegan (VicRoads), Ms Alyson Dalton (Dédale Asia-Pacific), Ms Samantha Cockfield (TAC) and Superintendent Peter Keogh (Victoria Police).

We also wish to thank the following people for their valuable contributions during the conduct of this research:

- Dr Janet Anderson (formerly MUARC) for her early input into the project;
- Dr Scott Shappell for correspondence regarding the human factors analysis and classification system;
- Mrs Matoula Leichman for her assistance in organising the human error workshop; and
- Ms Nicola Fotheringham (MUARC) for her assistance with the conduct of the workshop.

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# Chapter 1 Introduction

The work described in this report represents the second phase of this research program, the overall aim of which is to develop error-tolerant intersections in Victoria and an error tolerant road transport system in Australia. The purpose of this phase of the research program was to develop a conceptual framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole. The framework was developed by the authors on the basis of a comprehensive review of the literature surrounding the construct of human error and of contemporary error management programs and techniques from other safety-critical domains that was conducted during the first phase of this research program.

## 1.1 Research Activities

The research described in this report comprised the following three stages.

1. Development of a conceptual framework for promoting error-tolerance within the Australian road transport system. On the basis of the work conducted during Phase 1 of this research program, a conceptual framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole was developed. The framework contains the methods with which to collect and analyse error-related data and also a number of error management approaches designed to reduce, eradicate or manage road user error and its contributory conditions.
2. Investigation of potential error management applications within road transport. To investigate the potential application of the error tolerance framework within the Australian road transport system, a series of exploratory error management applications were reviewed in a road transport context. This included relating the systems perspective approach to the Australian road transport system, analysing a series of road traffic accidents using a systems perspective-based approach, developing a prototype model of road user error and prototype road user error and latent condition classification schemes, and using the SHERPA approach (Embrey, 1986) to predict road user error for an intersection scenario. In addition to the exploratory applications described above, further error data collection and management concepts were discussed with regard to their potential application within the Australian road transport system. This included investigating the use of accident reporting and investigation, incident or near-miss reporting, observational study, questionnaires and interviews to gather error-related data within road transport and finally identifying a number of potential error management strategies that could be used within the Australian road transport system.
3. Human error workshop. To gather feedback on, and to refine the proposed error tolerance framework, a workshop was convened by MUARC. The workshop involved a number of project stakeholders and also subject matter experts (SMEs) from the road transport and other safety critical domains.

This report describes the work conducted during each of the research phases identified above, and presents the key findings from each. The framework for promoting error tolerance within the Australian road transport system is presented in chapter 2, along

with the exploratory road transport error management applications, discussions of potential error management approaches, and the results of the human error workshop. Finally, the conclusions derived from this phase of the research program are presented in chapter 3, along with recommendations for further research in this area.

# Chapter 2 Toward a Framework For An Error Tolerant Australian Road Transport System

## 2.1 Introduction

This phase of the research program involved the identification of potential applications of existing human error theory, approaches, methodologies and programs, developed and applied in other domains that could be used as part of an error management program in the Australian road transport system. It was intended that the applications identified would form a framework that could be used to aid the development of an error tolerant road transport system within Australia. Additionally, it was intended that the methods required for the pilot study to be designed and conducted during the next phases of this research program would be extracted from the proposed framework.

In the preceding phase of this research, a review of the literature on human error and the human error-related research to date in road transport, and of the different error management approaches employed in safety-critical domains was conducted. It was concluded that the construct of human error has previously received only limited attention within road transport, and that the majority of human error-related research in road transport has taken a *person-based*, rather than a *systems* approach to addressing human error. Further, it was concluded that the development and implementation of error management programs within road transport has been only minimal, and that there is great scope for further investigation into road user error, its causal factors, and its management within the Australian road transport system.

With regard to potential error management programs, the review indicated several things: that the main purpose of error management programs within complex systems is to limit the occurrence of errors and latent conditions and to create more error-tolerant systems; that they depend on the collection of accurate data on errors and their contributory causes; that there are numerous error management techniques available to support the implementation of error management programs; and that there have been only limited attempts to implement human error management programs and techniques within road transport worldwide. Additionally, the review indicated that a suitable approach to error management in complex sociotechnical systems, such as road transport, must take into account several issues:

- that regardless of experience, skill-level, technological support, training and other factors, errors are consistently, and always will be, made by actors within complex systems;
- in addition to the errors made by operators performing activity within the system, latent conditions reside throughout the different organisational levels of the system; and
- accident causation in complex, dynamic systems typically involves a complex interaction between latent or error causing conditions and errors made by operators performing activity within the system.

Therefore it was concluded that the key principles of error management within such systems are the recognition of the fallible nature of humans, the acceptance that errors are inevitable, the identification and classification of the different errors and latent conditions within the system in question, and the development of strategies designed to enhance error tolerance throughout the system. Rather than attempt to enhance system safety through the total eradication of errors, systems are now being made safer by increasing their tolerance of errors. In relation to road transport, this means that despite road safety professionals' best efforts, interventions, strategies, new technologies and countermeasures will never completely eradicate road user error. Drivers, pedestrians, and other road users will continue to make errors for as long as the road system exists.

The fallible nature of road users must be recognised and the inevitability of error occurrence accepted. Rather than focusing entirely upon removing road user error through increased training, awareness campaigns and enhanced technology, effective error management in the road transport domain should also focus on increasing the road transport system's tolerance of error. Error tolerance within the Australian road transport system must be enhanced through the use of targeted error tolerance strategies based on the collection and analysis of specific error data. Error tolerance can be enhanced through road infrastructure design, road furniture design, vehicle design and error management driver training.

The implementation of such an approach within the Australian road transport domain requires not only a paradigm shift in terms of thinking, but also investigation regarding the potential application of a number of different human error theories, methods and techniques (developed in other domains) in the road transport domain. For an error tolerant framework to be implemented within the Australian road transport system, our current understanding of human error needs to be enhanced considerably. Therefore, it is recommended that the implementation of an error management or error tolerance framework within the Australian road transport domain includes a number of approaches designed to gather and analyse human error-related data which will in turn be used to contribute to our knowledge of the construct. Only then can effective error tolerance strategies be designed, developed and implemented. The review of human error theory and risk management methods and techniques indicates that there are a number of different theoretical perspectives, approaches and methodologies that could be used for this purpose. These methods include observational study, questionnaires, interviews, incident or near-miss reporting systems, HEI techniques, accident reporting, analysis and investigation techniques, human error models, and error classification schemes and taxonomies.

## **Open Versus Closed Systems**

Of the systems in which error management programs have historically been employed in the past, the majority tend to be characteristic of so-called 'closed' (as opposed to open) systems. A closed system is an organisational system in which behaviour is almost completely controlled through the use of well-defined and enforced procedures, rules, regulations, and technology. Examples of closed systems include civil air transport, nuclear power generation, and air traffic control. In these systems, the behaviour of those performing activity (e.g. pilots, nuclear power plant control room operators, and air traffic controllers) is strictly controlled by standard operating procedures, rules and regulations and by the technology that they use. Behaviour is constrained to a point where only those actions required for safe and efficient performance are permitted, and any deviation outside of the required behaviour often leads to reprisals or

punishment of some sort. The humans performing activity in closed systems have also typically graduated from similar training programs, and receive regular retraining to ensure that the skills required for performing activity are maintained. Prior to commencing employment in such systems, people are also screened or tested to see if they are of a suitable level of capability (e.g. intelligence, skill, mental capacity, physical capability etc) and so work with people who are of a similar level of capability as themselves. In addition, the technological artefacts used for performing activity in closed systems are regularly maintained and updated, and are required to pass regular stringent health and safety tests.

In an open system, however, behaviour is not completely constrained by rules, regulations, and procedures, and there is more latitude for behaviour. The road transport system is characteristic of an open system, in that road users (despite being constrained to some extent by laws, rules and regulations) have greater latitude for behaviour than do operators in closed systems. Violational behaviour, in particular, is less restricted than in closed systems, and is more frequent as a result. Additionally, the road users who share the system possess varying degrees of skill and ability, and use equipment (e.g. vehicles) of varying condition, standard and capability.

Historically, error management techniques have been employed in closed systems, and the majority of human error management techniques and programs discussed during the first phase of this research have been implemented in closed, rather than open systems. This has been so for a number of reasons. The nature of closed systems is such that it allows error management programs to be more effectively enforced, and the potential for successful implementation is thus greater than in open systems. Further, the range of behaviours permitted in open systems may be such that it is more difficult to identify the different types of errors that are being made by humans performing activity in the system.

Perhaps the key difference between open and closed systems with regard to error management is that in closed systems, participation in such programs can be effectively enforced, whereas in open systems there is no way of enforcing participation in error management schemes. Workers in closed systems are required to participate in error management programs (e.g. incident reporting) as part of their job. This is not so in road transport and the level of accident reporting and investigation seen within road transport is an example of this. Of the accidents that occur, only a small proportion may be reported, and of those that are reported only a very small proportion are investigated. A number of accidents go unreported as drivers may want to avoid reprisals, such as punishment or increased insurance costs. There is no way in which accident reporting can be effectively enforced. However, in a closed system such as the civil aviation domain, all accidents, regardless of size and consequence are reported and investigated to some extent, and this can be enforced by the relevant authorities. Such enforcement may be difficult to implement within road transport due to its open nature.

The authors acknowledge that implementing error management approaches in an open system such as road transport represents a formidable task, and that it is one of the reasons why selected error management approaches (e.g. incident reporting systems) have not historically been developed and implemented in a road transport context. However, we believe that there is significant potential for implementing error management approaches similar to those employed in open systems within road transport, provided that they are developed on the basis of the collection and analysis of accurate error data from the road transport domain.

Although different in the ways described above, open and closed systems are alike in that the humans performing activity within them make errors of a similar nature, and various contributory factors residing throughout the system are involved in the production of these errors. We strongly believe that it is feasible to incorporate error management techniques into road transport, and that the open nature of the road transport system would not inhibit the data collected and results gained from the use of such a program. We acknowledge that the nature of the road transport system will impact the way in which such approaches are used, but feel that there is sufficient evidence within the literature to suggest that such approaches can indeed work within a road transport context.

The literature review conducted during phase 1 of the project identified a number of instances where error management techniques (originally developed for use in other 'closed' systems) have been successfully applied in road transport. For example, on the basis of an observational study of road user error at over 30 problematic road transport sites, Wierwille et al (2002) developed and successfully applied a crash contributing factors taxonomy of latent conditions and driver errors in the analysis of road traffic incidents and accidents. Ljung and Huang (2002) developed and used the driver reliability error analysis method (DREAM) in the analysis of road traffic accidents with some success. DREAM is an adaptation of the cognitive reliability and error analysis method that was originally developed for use in systems such as civil aviation, rail transport and nuclear power. In addition to this, a number of validation studies have demonstrated the sensitivity of error prediction approaches in so-called open systems (e.g. Baber & Stanton, 1996; Stanton & Stevenage, 1999).

## **Toward a Framework for Error Tolerant Intersections and an Error Tolerant Australian Road Transport System**

On the basis of the work conducted during Phase 1, a conceptual framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole was developed. This involved identifying potential human error-related applications, developed and applied in other domains, that could be used in the road transport domain as part of an error management program. The framework contains both the methods with which to collect and analyse error-related data and also a number of error management approaches designed to reduce, eradicate or manage road user error and its contributory conditions. It is recommended that further error management strategies are then developed on the basis of the collection and analysis of human error-related data.

The framework was proposed as a way of increasing our understanding of road user error and enhancing error tolerance at intersections and in the general road transport system. The novelty of the framework is that it attempts to make error-data collection, error management and error tolerance strategy development standard components of the overall working system, rather than part of reactive error-related studies. The review of human error theory and risk management methods and techniques indicated that there are a number of different theoretical perspectives, approaches and methodologies that could potentially be used in the Australian road transport domain. These potentially applicable methods included observational study and road user interviews and questionnaires, incident or near-miss reporting systems, HEI techniques, accident reporting, analysis and investigation techniques, human error models, and error classification schemes and taxonomies. On the basis of human error research conducted in other complex sociotechnical systems, the authors propose that the following potential human error-related

applications in the Australian road transport system be investigated as the first steps in the development of an error tolerant road transport system in Australia:

- application of existing human error theory in the road transport domain;
- development of a human factors-oriented road transport accident reporting tool;
- development of a road transport incident or near-miss reporting system;
- development of a road user error classification scheme or taxonomy;
- development of a road system latent condition classification scheme or taxonomy;
- development of road user error and latent condition databases;
- development of a valid human error identification technique for road transport;
- development of a road transport-specific error management technique, similar to the TRIPOD Delta and REVIEW error management approaches used in the oil exploration and production and rail transport domains;
- development of error tolerance strategies (e.g. infrastructure and in-car technology design) and policies (e.g. legislation and advertising campaigns) designed to increase error tolerance and/or mitigate error and its consequences within the road transport domain; and
- development of error management driver training interventions.

The human error-related applications presented above can be combined to form the basis of a framework designed to facilitate the development of error tolerant intersections in Victoria and an error tolerant road transport system in Australia. It is also intended that the error pilot studies designed for the next phase of this research are extracted from the framework presented below. It is the opinion of the authors that the provision of such a framework could potentially enhance error tolerance within the Australian road transport system and in turn could enhance road user safety considerably. The framework for an error-tolerant road transport system is presented in figure 2.1. The internal structure of the framework can be broken down into the following four levels:

1. *Data collection.* This provides the techniques necessary for the collection of pertinent data regarding the nature of latent conditions and errors within the road transport domain. It is proposed that the data collection component of the error tolerance framework could comprise a road transport-specific incident reporting system, observational study of high risk road infrastructures (e.g. intersections), interviews with road users, a road user error questionnaire, and also an accident investigation tool designed to facilitate the accurate reporting of accidents within the road transport domain.
2. *Data analysis.* The data analysis component is used to analyse the data collected. Subsequent analysis will allow the classification of the latent conditions and errors involved in road transport incidents and accidents.
3. *Error identification.* This is used to identify, both qualitatively and quantitatively, the different types of latent conditions residing in, and errors made in, the road transport system. The database of latent conditions and errors that have occurred at intersections and within the road transport system in general will then be used to refine and validate classification schemes

of road user error and latent conditions and develop a road transport specific HEI technique which could be used to predict human error within the road transport system.

4. *Error tolerance strategies.* The final component of the error management framework involves the development and application of strategies designed to minimise error occurrence and increase error tolerance within the road transport system and countermeasures designed to mitigate the latent conditions and errors identified previously. It is proposed that a structured error management technique be developed and implemented as part of this component. Additionally, it is proposed that targeted error tolerance strategies be developed and implemented based upon the data derived from the previous three layers of the framework. Error tolerance strategies might include the design of error tolerant road infrastructure, the development and application of error management training, the design of vehicles and in-vehicle technology (e.g. ITS), the development and enforcement of road legislation and also the use of advertising campaigns.

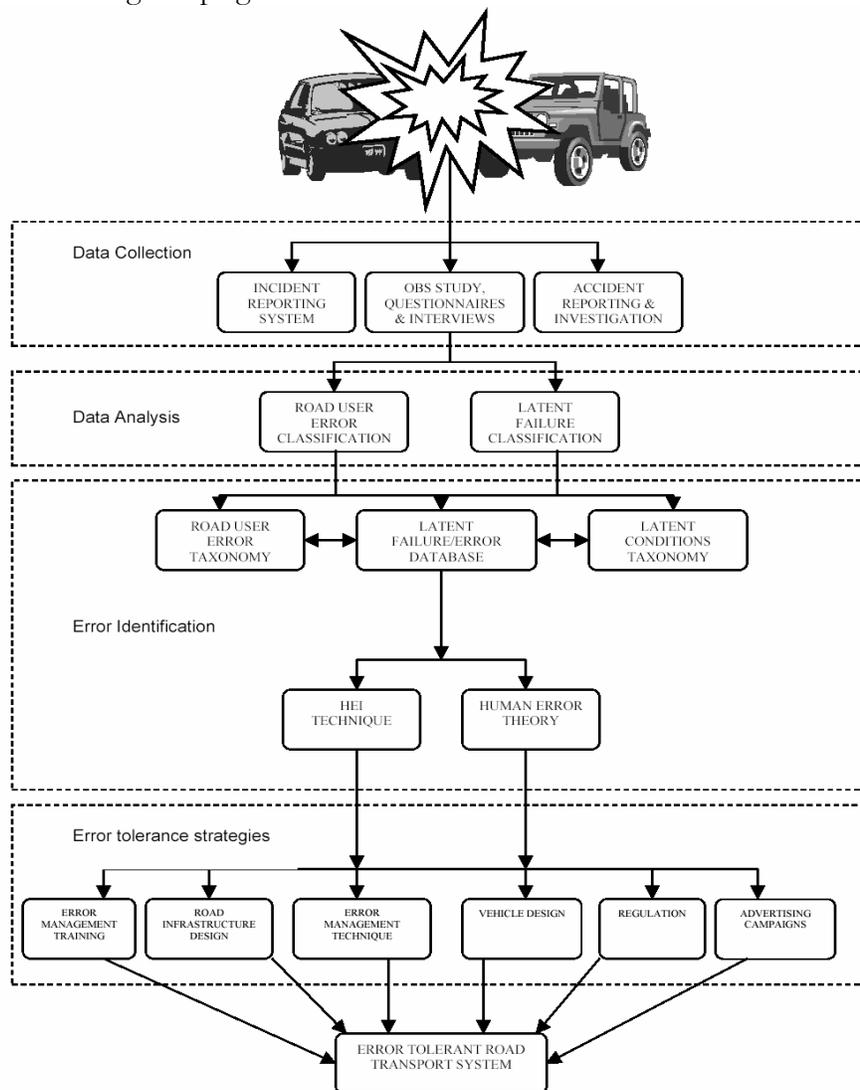


Figure 2.1. A framework for error tolerant intersections and an error tolerant road transport system.

The following section discusses in more detail the different application areas within the framework presented in figure 2.1. In particular, a discussion of how each of the different approaches could potentially be implemented within the Australian road transport system is presented.

## **2.2 Taking the Systems Perspective Approach to Human Error in the Australian Road Transport System**

The majority of human error-related research conducted in road transport has adopted a person-based perspective on error. Additionally, effective error management programs take a systems perspective approach to error, considering not only the errors made by individual operators within the system, but also the role of various latent conditions that reside within the system. Taking this and the findings from phase 1 of this research program into account, it is apparent that the systems perspective or Swiss cheese model of human error proposed by Reason (1990) offers a suitable framework for application in the road transport domain. Amongst other things, the potential benefits associated with the application of Reasons model in the road transport domain include:

- the identification of the different organisational levels within the Australian road transport domain;
- the identification and classification of the different latent or error-causing conditions residing at each of the different organisational levels within the road transport domain;
- the identification and classification of the errors committed by drivers, pedestrians and other road users within the road transport domain;
- the provision of a framework for analysing accidents and incidents occurring within the road transport domain; and
- a shift in focus from the role of the individual road user to the system wide failures involved in accident causation.

A systems perspective-based model in the road transport domain could lead to a greater understanding of the latent conditions and road user error within the road transport system, which in turn could inform the development of strategies designed to promote error tolerance within the road transport domain. In order to apply a systems perspective-based model of error within the Australian road transport system, two key questions need to be addressed:

- who makes the holes in the cheese? The systems perspective model of human error works by identifying the latent conditions that reside within a particular system, and also the errors made by operators performing activity within that system. For a systems perspective approach to be applied in the road transport domain, a breakdown of the different organisational bodies, authorities and operators, ranging from federal road transport authorities to road users that occupy the different organisational levels within the Australian road transport system, is required. A breakdown of the different organisations and actors within the system permits the identification of the sources of latent conditions and errors within; and

- what are the holes in the cheese? Once the different levels have been determined, the different latent conditions and errors that make the holes at each of the organisational levels within the road transport system need to be defined to develop countermeasures and error mitigation strategies.

An initial attempt was made to determine the organisational structure of the Australian road transport system based upon the systems perspective model. This involved identifying the different road transport-related government bodies, road transport authorities and road users currently active within the Australian road transport system. According to Reason (1990) the following basic levels are a common feature of productive systems:

- decision makers. Includes the architects and high level managers of the system in question. According to Reason (1990) they set the goals for the system and they direct, at a strategic level, the means by which these goals should be met;
- line management. The departmental specialists who implement decision maker strategies, including operations, training, sales, maintenance, finance, procurement, safety, engineering support and personnel (Reason, 1990);
- preconditions. The qualities held by both machines and people e.g. reliable equipment, skilled workforce, codes of practice etc;
- productive activities. The actual performance of humans and machine; and
- defences. The safeguards designed to prevent injury, damage or costly outages.

A systems perspective model of the Australian road transport domain is presented in figure 2.2.

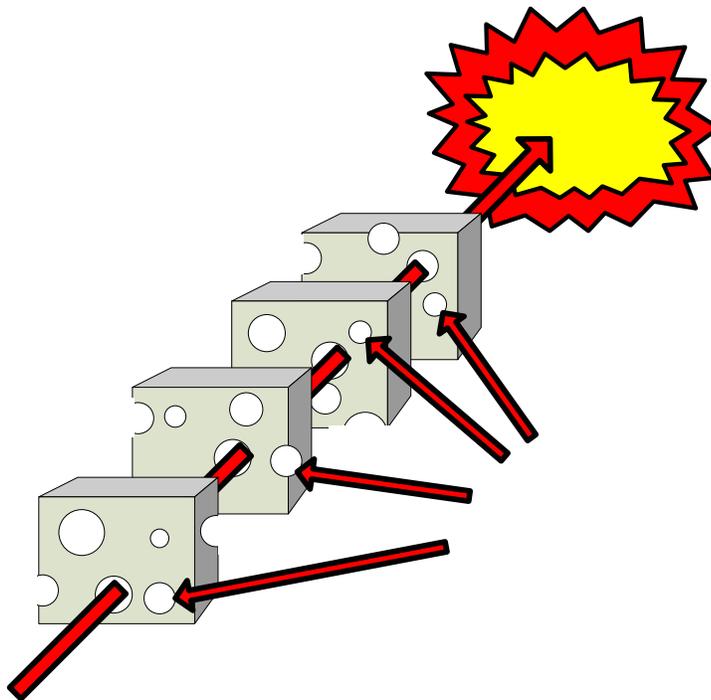


Figure 2.2. Road transport systems perspective organisational levels.

The breakdown of the different levels within the Australian road transport system permits the identification of the potential sources of latent conditions within it. In addition to the specification of the different organisational levels within the road transport system, the exact nature of the latent conditions and errors at each of the levels also needs to be defined. The definition of the latent conditions and errors requires considerable research effort and it is beyond the scope of this document to attempt to comprehensively and accurately describe such conditions. However, to demonstrate the potential classification of the latent conditions and errors within the road transport system, the HFACS civil aviation accident investigation approach (Wiegmann & Shappell, 2003) was used to provide examples of the different latent conditions and active errors at the following levels within the Australian road transport domain:

*Unsafe acts.* Refers to those errors committed by operators within the system that lead directly to an incident or accident. In road transport, the unsafe acts level therefore refers to those errors committed by road users (e.g. drivers, pedestrians, cyclists etc) that lead to an accident or incident. HFACS defines two categories of unsafe acts, errors and violations. Errors refer to activities (or failure to perform activities) performed by actors in the system that result in undesired outcomes. Violations refer to those behaviours that deviate from accepted procedures, standards, and rules (e.g. speeding).

A classification scheme similar to the unsafe acts classification scheme employed by HFACS could be used to identify the different road user errors involved in road transport accidents and incidents. For example, skill-based errors, such as failed to prioritise attention, task overload, distraction and failure to see and avoid are all examples of error types that occur frequently in the road transport domain. The authors acknowledge that the HFACS unsafe acts taxonomy was developed specifically for the aviation domain, and it is therefore recommended that a road transport domain-specific classification scheme be developed.

*Preconditions for unsafe acts.* Preconditions for unsafe acts are the underlying latent conditions that contribute to the occurrence of the unsafe acts described above. Within the HFACS approach the preconditions for unsafe acts category comprises the following three categories: conditions of operators, environmental factors and personnel factors. Examples of preconditions for unsafe acts from each category that are applicable to road transport are presented below.

- Environmental factors

*Physical Environment* – Weather conditions, Terrain, Lighting.

*Technological Environment* – equipment/controls design, display/Interface characteristics, automation.

- Condition of road users

*Adverse mental states* – loss of situational awareness, complacency, stress, overconfidence, poor vigilance, task saturation, alertness (drowsiness), impatience, mental fatigue, channelised attention, distraction.

*Adverse physiological states* – medical illness, physical fatigue, intoxication, effects of medication.

*Physical/Mental Limitations* – visual limitations, insufficient reaction time, information overload, inadequate experience for complexity of situation, incompatible physical capabilities, lack of sensory input.

- Personnel factors

*Crew Resource Management* – lack of teamwork, lack of assertiveness, poor communication, coordination.

*Personal Readiness* – failure to rest, inadequate training, self-medicating, overexertion, poor dietary practices, pattern of poor risk judgement.

Again, the authors recommend that a classification scheme for the preconditions for unsafe acts be developed for the road transport domain. Such a scheme could be used to determine the preconditions or latent conditions involved in accidents and incidents that occur within the road transport domain.

*Organisational Influences.* Addresses the fallible decisions made at political, board and management levels. HFACS uses three categories of organisational influence failures: resource management, organisational climate, and organisational process. Examples of organisational influence failures for the road transport system are given below.

- Resource Management

*Human resources* – training

*Monetry/Budget resources* – excessive cost cutting

*Equipment/Facility resources* – poor vehicle. Poor vehicle cockpit, unsuitable equipment, failure to correct known design flaws

- Organisational Climate

*Policies* – drugs and alcohol, accident investigations

*Culture* – norms and rules, organisational customs, values, beliefs, attitudes

- Organisational Process

*Operations* – failed to correct inappropriate behaviour/identify risky behaviour, failed to correct a safety hazard, failed to initiate corrective action, failed to report unsafe tendencies

*Procedures* – performance standards, clearly defined objectives, procedures/instructions about procedures

*Oversight* – established safety programs/risk management programs, managements monitoring and checking of resources, climate, and processes to ensure a safe work environment.

It is the opinion of the authors that a road transport error classification scheme, similar to the HFACS approach described previously in this report, would be of great use within the road transport domain. Such an approach could potentially be used in the analysis of error data, such as accident report data, which in turn could inform the development of road user error and road transport system latent conditions taxonomy. To demonstrate the potential of such an approach, a series of exploratory analyses were conducted.

## Road Transport Flavoured Swiss Cheese – An Example Analysis

An application of Reasons (1990) systems perspective model within the road transport domain was described in the previous chapter. To further demonstrate the potential application of the systems perspective model in road transport, an analysis of three accident scenarios was conducted. The first is of a fictional accident to demonstrate the potential use of the model, and the second and third accident analyses are based upon accident scenarios derived from Victorian Police accident reports.

### Accident A

The first accident occurred on a freeway just outside a large city at approximately 11pm. The conditions were dark and wet. The accident involved a collision between two vehicles, and a resultant collision between the vehicles and nearby road furniture. A black 4WD vehicle travelling in the middle lane of the freeway began to move into the fast lane to pass the vehicle in front. Unfortunately, the 4WD vehicle driver (driver A) did not look over his shoulder and failed to see a grey sedan approaching in the fast lane. As the grey sedan (driver B) was travelling approximately 10km over the speed limit there was little chance for the 4WD to avoid it and the two vehicles collided. As a result of this, both drivers swerved away from each other to avoid further contact. The black 4WD driver lost control of the vehicle and crashed into the central safety barrier, and the grey sedan driver swerved off the road and collided with a tree close to the road. Both vehicles were damaged beyond repair and both drivers' sustained injuries. Initial blame was apportioned to the 4WD driver as he failed to make the necessary check (glance over shoulder) to see if the outside lane of the freeway was clear. More in-depth analysis reveals that the grey sedan driver was a recently qualified young male driver who was carrying 4 passengers and that the drivers were also passing a large freeway advertisement immediately prior to the incident. Additional features of the incident were limited freeway signage and lighting.

To demonstrate the potential use of the systems perspective approach in the road transport domain, an analysis of the accident described above was conducted. A summary of the analysis is presented in figure 2.3.

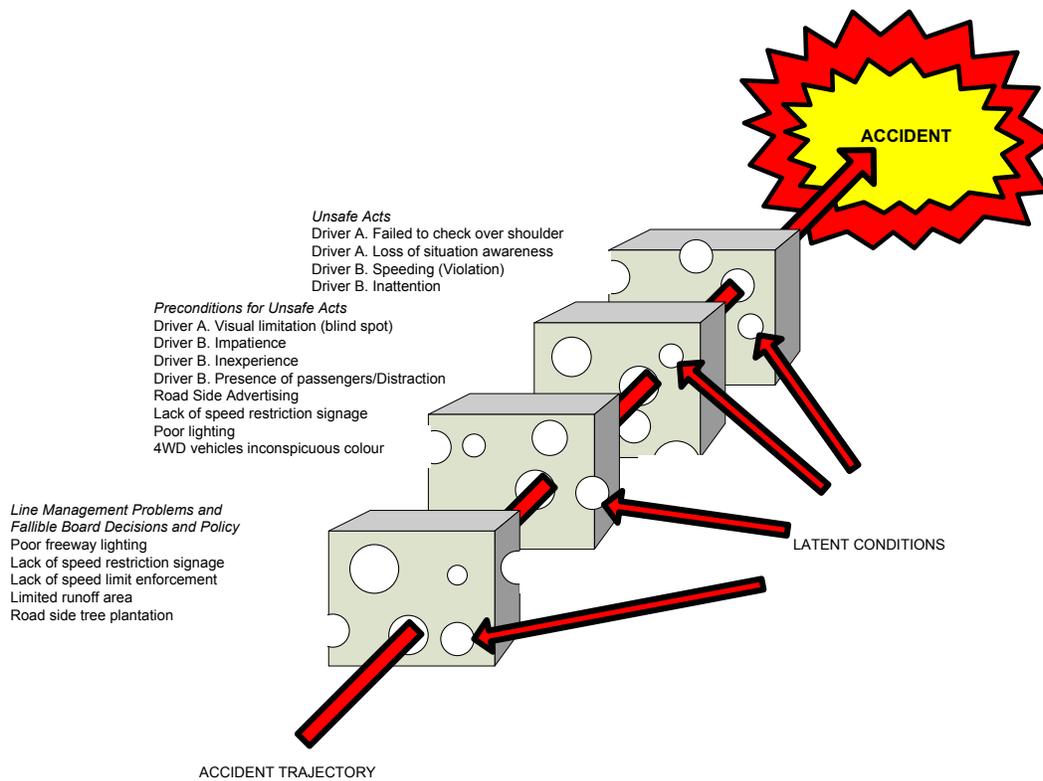


Figure 2.3. Example systems perspective analysis of accident A.

A systems perspective highlights the combined role of latent conditions and the errors made by the drivers of both vehicles in the accident. Rather than apportioning blame solely to driver A for omitting to check over his shoulder, various contributory factors are identified in relation to road infrastructure, vehicle design, both drivers, and environmental conditions. The analysis identifies four unsafe acts by the drivers that led to the accident. These were a failure by driver A to make an over the shoulder check that the fast lane was clear and the resultant loss of situational awareness. At the time of the accident driver B was also speeding, a violational error, and his failure to see the 4WD in time is classed as inattention to the road situation. There were many contributory factors involved.

The precursors for unsafe acts include the visual limitation of driver A caused by the blind spot in his mirror, haste to get home quickly, inexperience and also the presence of passengers in the case of driver B. Road infrastructure-related precursors for unsafe acts included the presence of a large roadside advertising board (distracts driver attention), a lack of speed limit signage on the freeway (non-comprehension of current speed limit), poor lighting (low visibility) and inconspicuous colouring (black) of the 4WD (reduced visibility). Additional precursors for unsafe acts can be identified in the local or environmental conditions which were dark (reduced visibility) and wet (skid potential). Line management and poor board decision and policy problems included a decision by the local road authority not to provide additional lighting or speed signage on the freeway, a lack of speed limit enforcement by the local road authorities (e.g. speed cameras) and the relevant law enforcing bodies (e.g. police presence), the planting of trees in close proximity to the roadside, and the lighting and signage regulations.

The following analyses are based upon accident scenarios that were constructed from Victoria Police accident reports forms.

### **Accident B**

Vehicle A, travelling along X road disobeyed a traffic control signal and continued through an intersection, colliding with Vehicle B. The following additional information can be derived from the accident report form.

- Road surface type: paved;
- Road surface conditions: dry;
- Light conditions: dusk; and
- Atmospheric conditions: clear.

Using a systems perspective to analyse this crash, the unsafe act was identified as the driver of vehicle A disobeying the traffic control signal and his or her subsequent continuation through the intersection. This can be classified as a violation. However, whether it was an intentional violation (i.e. the driver intentionally disobeyed the traffic control signal) or an unintentional violation (i.e. the driver did not see the traffic control signal or mis-perceived it) cannot be determined from the accident report form. Similarly, it is difficult to identify any preconditions for unsafe acts that may have been involved (e.g. equipment, training, adverse mental states) from the information in the accident report. The ambient lighting at dusk may have played a part, but without consulting the driver of vehicle A, it is impossible to know. In addition, it is difficult to identify any line management problems or fallible board decisions that may have been involved because such information is not included within the report.

### **Accident C**

Vehicle A (Motorcycle) was attempting to make a right hand turn at an intersection in front of an oncoming 4WD, vehicle B. Vehicle B passed through a green traffic signal and collided with vehicle A. The following additional information can be derived from the accident report form.

- Road surface type: paved;
- Road surface conditions: dry;
- Light conditions: dark-street lights on; and
- Atmospheric conditions: clear.

Using the systems perspective to analyse this crash, the unsafe act was identified as the driver of vehicle A attempting to make a right hand turn in front of the oncoming vehicle B. Again, the nature of the data contained in the accident report limits the analysis. For example, the unsafe act of attempting to make a right turn could have been an intentional violation or an unintentional violation. Similarly, from the information in the accident report it is difficult to identify any preconditions for unsafe acts that may have been involved. The dark lighting conditions may have played a part in the accident, but without consulting both drivers it is impossible to derive this from the report. In addition, it is also difficult to identify any line management problems or fallible board decisions that may have been involved, because such information is not contained in the report.

The two analyses above demonstrate the various problems associated with analysing the errors and latent failures in road transport accidents from the information collected with current reporting procedures. First, the information in the accident report forms is not detailed enough to permit accurate error analysis. While a limited amount of error-related information can be derived, this is not sufficient to permit an accurate and exhaustive error analysis, and the analyst must rely heavily on subjective judgement to identify errors and latent failures. Second, the absence of accident accounts from the road users also limits the analysis of errors. For example, in accidents B and C the unsafe acts were identified as violations. However, without talking to the road users involved it is impossible to determine the type of violation (unintentional or intentional) and the causal factors involved. This limits the extent to which further latent failures and contributory factors can be identified.

The analyses described demonstrate the potential of a systems perspective model as an accident or incident investigation tool. The utility of such an approach lies in the ability to identify errors and latent conditions throughout the system that contributed to a particular accident, and also the removal of a driver focussed blame culture within the road transport domain. When post-crash blame is attributed to individual drivers only, the reasons why the driver failed and the interaction between various complex contributory factors that preceded the incident are ignored. Consequently, safety interventions and countermeasures are focussed on just one system feature, rather than on the multiple features that combined to cause the accident. This point of view certainly has relevance within the road transport system, where safety interventions designed to reduce accidents are typically aimed at the driver (e.g. training, advertising campaigns) and ignore the role of system wide latent conditions. A systems perspective approach ensures that such latent conditions are considered in the development of accident countermeasures. Appropriate countermeasures deriving from the latent conditions identified have the potential to minimise the occurrence and consequences of errors in other crash scenarios.

Despite the apparent potential utility of a systems perspective approach, two key problems associated with the model were identified. First, the model lacks a taxonomy of road user errors and second the model lacks a taxonomy of latent failures at each of the different levels within the road transport domain. As a result, a high level of dependence is placed on the subjective judgement of the analysts involved in identifying and classifying the errors and latent conditions involved. It is recommended that classification schemes or taxonomies of latent conditions and errors be developed for the road transport domain. This is discussed in the next section.

In summary, the use of a systems perspective approach in road transport accident analysis appears to be extremely useful for identifying the road user errors and latent failures involved in accidents. It is the opinion of the authors that using such a system for accident analysis could lead to the development of a database of errors and latent conditions which in turn could be used to inform the development of error tolerance strategies and appropriate error countermeasures. The exploratory analysis indicated, however, that the accident reporting system currently employed in Victoria does not support error and latent condition analysis, due to the lack of detail in the accident reports.

## 2.3 Latent Condition and Error Classification

For effective human error research to be conducted and for the development of suitable error tolerance strategies and countermeasures, a classification of the different latent conditions and road user errors that occur within the road transport domain is required. It is recommended that road user error and latent conditions classification schemes be developed specifically for use within the road transport domain. The classification of errors and latent conditions is required at the various different actor and organisational levels within the road transport domain, including drivers, pedestrians, other road users, different enforcement agencies, and also the various different regulatory, governing and political bodies. Each of these groups makes errors and decisions that lead to latent conditions that potentially impact road safety. A system for classifying errors in the road transport domain has the potential to provide:

- an understanding of the causal processes (latent conditions and road user errors) involved in road transport accidents and incidents;
- information that can lead to the development of countermeasures and error tolerance strategies designed to target the various latent conditions and errors identified;
- a classification scheme to aid the reporting, investigation and analysis of road transport accidents and incidents;
- a classification scheme to aid the identification of specific trends in accident causation;
- a means to provide both a quantitative and qualitative assessment of the latent failures and errors involved in accidents and incidents in the road transport domain;
- a means to evaluate alternative road transport-related designs (e.g. vehicle cockpits, road infrastructure, signage etc); and
- a means to *a priori* estimate risk probabilities.

It is therefore recommended that latent condition and road user error classification schemes be developed. Specific data on latent conditions and road user errors is required for this. For example, Shappell & Wiegmann (2000) used over 300 naval aviation accident reports from the U.S. Naval Safety Center to develop a taxonomy of unsafe operations in the aviation domain. Additionally, the original taxonomy was refined using data from other military and civil organizations. During the development of a taxonomy of design induced pilot error, Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann & Dekker (2003) used a questionnaire to gather error occurrence information from civil airline pilots. The importance of error data collection was emphasised in the phase 1 report. It is the opinion of the authors that road user and latent condition error classification schemes should be developed based upon the following information:

- existing error classification schemes and error taxonomies (e.g. HFACS, DREAM);
- accident reports;
- information derived from the analysis of road traffic accidents (using data from accident databases);
- information collected from a road transport incident or near-miss reporting system; and
- information collected from on-site observational study, questionnaires and interviews.

To investigate error classification in road transport further, a prototype model of road user error was developed. The model of road user error highlights the complex interaction between contributing conditions and road user behaviour that lead to road user errors being made. In addition to the model, prototype road transport contributing conditions (i.e. latent conditions) and road user error classification schemes were developed on the basis of a review of the existing latent condition and error classification schemes available in the literature. It is intended that the taxonomies will be used to classify the contributing condition and road user error data that is collected during the phase 3 and 4 pilot study and also that the data collected be used to refine and validate the taxonomies.

The prototype model of road user error and contributing conditions is presented in Figure 2.4. The model demonstrates how inadequate conditions within the road transport system can impact road user behaviour in a way that leads to errors being made. A taxonomy of the external error modes that drivers may make when affected by these inadequate or contributing conditions is presented in the model. The model also presents a breakdown of the different contributing condition categories that can potentially lead to road user errors. Each of the contributing conditions categories are further sub-divided into specific contributing conditions (also presented in Tables 2.1 – 2.6). When present, contributing conditions might, either in isolation or in combination with one another, impact road user behaviour (cognitive and/or physical behaviour) in a way that contributes to road user error occurrence. The model presented in Figure 2.4 depicts the following five categories of contributing conditions that might impact road user behaviour in a way that leads to road user error of some sort:

1. Road infrastructure contributing conditions. Refer to those inadequate conditions residing within the road transport infrastructure, including road layout, road furniture, road maintenance and road traffic rules, policy and regulation-related conditions.
2. Vehicle contributing conditions. Refer to those inadequate conditions residing within the vehicles that are used within the road transport system, including human-machine interface (HMI), mechanical, maintenance, and inappropriate technology-related conditions.
3. Road User contributing conditions. Refer to the condition of the road user involved, including road user physiological state, mental state, training, experience, knowledge, skills and abilities, context-related and non-compliance related conditions.
4. Other Road User contributing conditions. Refer to the contributing conditions caused by other road users, including other driver behaviour, passenger effects, pedestrian behaviour, law enforcement and other road user behaviour-related conditions.
5. Environmental contributing conditions. Refer to the environmental conditions that might affect road user behaviour, including weather conditions, lighting conditions, time of day and road surface related conditions.

Contributing conditions from within each of the five categories presented above impact road user behaviour, both in terms of cognitive behaviour such as perceiving, planning and decision-making, and physical behaviour such as vehicle control tasks and visual scanning. In most cases the effect of these conditions on road user behaviour is only minimal, and most road users can cope with the conditions and still perform the required activity safely. In other cases, the effect of the conditions may be greater, but the road user in question is able to cope with the conditions (due to factors such as skill level and experience) and perform the required activity safely and without error. However, in some instances, the effect of the contributing conditions is sufficient

enough to cause the road user in question to make an error of some sort. Alternatively, the road user in question can also make errors that are not caused by the contributing conditions.

The model presented in figure 2.4 demonstrates the potential outcomes that are associated with road user error occurrence. These are that the error has no impact, the error is recovered from in some way, the error leads to another error or that the error leads to a safety compromising incident or accident of some sort. Alternatively, in extreme cases the contributing conditions can, in isolation or in combination with one another, lead to accidents and incidents not involving road user error; that is, the condition is such that it contributes to an accident or incident without the road users involved actually making an error. An example of this would be when the road surface condition is in such a bad condition (due to weather or lack of maintenance etc) that it may cause a vehicle to run-off the road and crash, without the driver in question actually making an error of some sort.

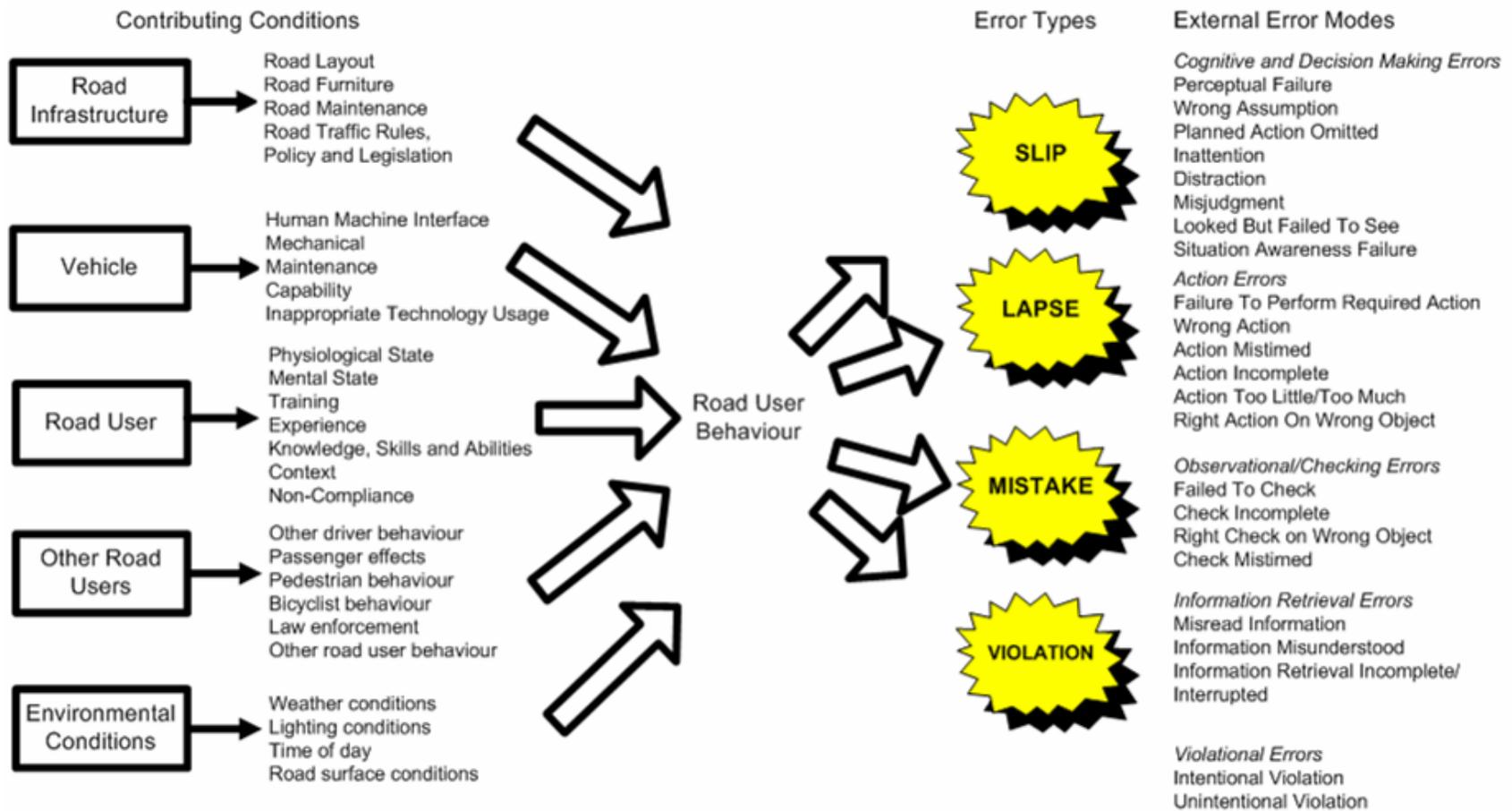


Figure 2.4. Prototype Road User Error and Contributing Conditions Model

## Road Transport Contributing Conditions Classification Scheme

Within the model of road user error, five categories of contributing conditions are presented. Each contribution category can be sub-divided into further specific contributing conditions. The prototype contributing conditions classification scheme was developed on the basis of a review of existing latent condition classification schemes and taxonomies, from both the road transport domain and from other safety-critical domains. A summary of the classification schemes reviewed is presented below:

### *Road transport classification schemes*

1. Crash contributing factors taxonomy (Wierwille et al, 2004).
2. DREAM classification schemes (Huang and Ljung, 2004).
3. Road transport general failure types (Wagenaar and Reason, 1990).
4. Driver error and incident causation factors (Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansfer & Castellan (1977).
5. Road environment and vehicle contributory factors taxonomies (Sabey and Taylor, 1980).

### *Non-road transport classifications schemes*

1. HFACS (Wiegmann & Shappell, 2003).
2. AcciMaps (Svedung & Rasmussen, 2002).
3. ICAM (BHP Billiton, 2001).
4. TRIPOD DELTA general failure types.
5. REVIEW railway problem factors.
6. PEAT contributing factors (Graeber & Moodi, 1998).
7. MEDA contributing factors checklist.
8. CPIT contributing factors.
9. REDA contributing factors.
10. TRACEr performance shaping factors (Shorrock and Kirwan, 2002).

Each classification scheme described above was combined to form a comprehensive taxonomy of contributing or latent conditions derived from a number of complex socio technical systems. Each condition was then reviewed with regard to its applicability to road transport. As a result, a set of prototype road transport-specific contributing conditions was developed. The prototype road transport classification scheme is presented in Tables 2.1 to 2.6.

Table 2.1. Road Infrastructure related contributing conditions

Category Group	Conditions Group	Conditions			
1. Road Infrastructure	a. Road layout	- Confusing layout			
		- Complex layout			
		- Inappropriate layout			
		- Illogical layout			
		- Unfamiliar layout			
	b. Road furniture	- Road markings		- inadequate road markings	
				- confusing road markings	
				- road markings obstructed	
		- Road signage		- signage obstructed	
				- unclear signage	
				- signage missing	
				- misleading or confusing signage	
				- Incorrect signage	
				- Inappropriate signage	
				- Inappropriate location	
			- Traffic control devices		- Not working
					- View obstructed
				- Inappropriate location	
		- Advertising		- Inappropriate location	
				- Obstructed view of traffic and signage	
			- Distracting		
	c. Road Maintenance	- Road works			
		- Other			
		- Road condition			
	d. Road traffic rules, regulation and policy	- Road markings			
- Traffic control devices					
- Signage					
- Other road furniture					
- Pedestrian area					
- Other					
- Illogical regulations					
- Inappropriate regulation					
- Confusing/misleading regulation					
- Other					

Table 2.2. Vehicle related contributing conditions

Category Group	Conditions Group	Conditions		
2. Vehicle	a. HMI	- Vehicle control design		
		- Interface design/layout		
		- Automation problem		
		- Other		
	b. Mechanical	- Engine failure		
		- Brake failure		
		- Steering failure		
		- Signal failure		
		- Other vehicle failure		
	c. Maintenance failure	- Engine		
		- Tyres		
		- Brakes		
		- Body		
		- Windscreen		
		- Lights		
		- Indicators		
		d. Use of inappropriate technology within vehicle	- Mobile phone	
			- Personal data assistant	
			- Laptop	
	- DVD player			
- Television				
		- Videogame		
		- Other		

Table 2.3. Road User related contributing conditions

Category Group	Conditions Group	Conditions
3. Road User	a. Physiological state	- Physical Fatigue
		- Drugs
		- Alcohol
		- Medication
		- Illness
		- Visual limitation
		- Physical limitation
		- Emotional distress
		- Other
		b. Mental state
	- Underload	
	- Mental Fatigue	
	- Loss of vigilance/alertness	
	- Loss of SA	
	- Complacency	
	- Distraction	
	- Mental limitation	
	- Overconfidence	
	- Stress	
	- Emotional distress	
	- Attitude	
	- Motivation	
	- Other	
	c. Task-related factors	- Lost
		- Get-home-it-is
		- Unfamiliar surroundings
		- Other
	c. Training	- Inadequate training
		- Unqualified/Underage driver
		- Education
		- Qualified in different jurisdiction
		- Other
	d. Experience	- Inexperience
- Acquaintance with vehicle		
- Acquaintance with road system		
- Over-familiarity with road		
- Over-familiarity with vehicle		
- Other		

	e. Knowledge, skills and abilities	- Insufficient skill
		- Insufficient knowledge
		- Insufficient ability
		- Poor technique
		- Other
	f. Understanding	- Failure to understand traffic laws and road rules
		- Failure to understand vehicle capability
		- Failure to understand traffic control devices
		- Failure to understand road markings
		- Failure to understand road layout
	g. Passenger effects	- Peer pressure
		- Distraction
		- Lack of assertiveness
		- Communication problems
		- Inappropriate behaviour due to passenger presence
	h. Non-compliance/Violation	- Intentional non-compliance/violation of road traffic rules and regulations
		- Unintentional non-compliance/violation of road traffic rules and regulations
		- Intentional violation of licensing laws
		- Unintentional violation of licensing laws

Table 2.4. Other Road User related contributing conditions

Category Group	Conditions Group	Conditions
4. Other Road User	a. Other driver behaviour	- Non-compliance/violation of traffic rules and regulations
		- Force road user to take avoiding action
		- Pressure road user to make manoeuvre
	b. Pedestrian behaviour	- Non-compliance/violation of traffic rules and regulations
		- Force road user to take avoiding action
		- Pressure road user to make manoeuvre
	c. Bicyclist behaviour	- Non-compliance/violation of traffic rules and regulations
		- Force road user to take avoiding action
		- Pressure road user to make manoeuvre
	d. Other road user behaviour	- Non-compliance/violation of traffic rules and regulations
		- Force road user to take avoiding action
		- Pressure road user to make manoeuvre

Table 2.5. Environmental related contributing conditions

Category Group	Conditions Group	Conditions
5. Environmental	a. Weather conditions	- Wet
		- Icy
		- Foggy
		- Excessive glare from sun
		- Snow
		- Rapid change in weather
		- Road flooded
		- Other
	b. Lighting conditions	- Dark
		- Light
		- Dusk
		- Dawn
		- Other
	c. Time of day	- Early morning
		- Morning
		- Afternoon
		- Evening
		- Late night
	d. Road surface conditions	- Wet
		- Slippery
- Other		

Table 2.6. Other contributing conditions

Category Group	Conditions Group	Conditions
6. Other	a. Law enforcement	- Actual lack of law enforcement
		- Perceived lack of law enforcement
		- Inappropriate law enforcement
		- Distraction due to presence of law enforcement agencies

## Road User Error Classification Scheme

A prototype classification scheme for the different road user error types was also developed, and is presented in Figure 2.6. The road user error classification firstly divides road user error into the following error types:

1. Slips. Those errors in which the plan or intention was correct but the execution of the required action was incorrect.
2. Lapses. Those errors involving a failure of memory or a failure to perform an intended action at the correct time or at all.
3. Mistakes. Those errors involving an inappropriate intention or incorrect decision followed by the correct execution of the required action.
4. Violations. Those errors involving behaviour that deviates from accepted procedures, standards and rules.

Next, the classification scheme presents a taxonomy of external error modes (EEM) or forms that the road user errors take. The road user EEMs are divided into the following error mode categories:

1. Cognitive and Decision Making Errors.
2. Action Errors.
3. Observation/Checking Errors.
4. Information Retrieval Errors.
5. Violational Errors.

The road user error classification scheme was developed on the basis of a review of the existing error taxonomies and classification schemes available in the literature. A summary of the error taxonomies and classification schemes reviewed is presented below:

### *Road transport classification schemes*

1. Crash contributing factors taxonomy (Wierwille et al, 2004).
2. DREAM classification schemes (Huang and Ljung, 2004).
3. Road transport general failure types (Wagenaar and Reason, 1990).
4. Driver error and incident causation factors (Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansfer & Castellan, 1977).
5. Road environment and vehicle contributory factors taxonomies (Sabey and Taylor, 1980).

### *Non-road transport classifications schemes*

1. HFACS (Wiegmann & Shappell, 2003).
2. ICAM (BHP Billiton, 2001).
3. SHERPA (Embrey, 1986) EEM taxonomy.
4. TRACEr (Shorrock and Kirwan, 2002) EEM taxonomy.
5. HET (Harris, Stanton, Marshall, Young, Demagalski & Salmon, In Press) EEM taxonomy.

6. THERP (Swain and Guttman, 1983) EEM taxonomy.

7. CREAM (Hollnagel, 1998) EEM taxonomy.

It is recommended that the prototype model of road user error and road user error and contributing conditions classification schemes presented above are used to classify the error data that is collected through the conduct of the error pilot study during the next phases of this research program. The error data collected will then be used to refine and validate the prototype classification schemes.

## **2.4 Accident Reporting and Investigation**

Error management programs in other domains are built on the collection of error and accident data. The analysis of accident data potentially offers a means of collecting error-related information in the road transport domain. However, it is apparent that there are a number of problems that may inhibit the collection of error-related information within accident reports in the road transport system. First, not all accidents in the road transport system are reported and investigated. A considerable proportion of accidents remain unreported, because the people involved may not wish to disclose details due to cost of insurance and disciplinary concerns. Additionally, the information recorded during current accident reporting procedures may not contain sufficient detail to permit the classification and analysis of error-related information. According to Grayson & Hakkert (1987; cited in Lourens, 1989), in-depth accident investigation studies are expensive and have produced little worthwhile information at great cost. Lourens (1989) points out that accident analysis in road transport suffers from problems related to the reporting of accidents, including underreporting, inaccuracy, and incompleteness. An initial review of the system currently employed by the road transport police in Victoria indicates that the current accident reporting procedure is inadequate for the collection and analysis of data on errors and latent conditions in accidents. The current system is used to collect information regarding the following categories of information only:

- 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 reference 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.

An exploratory analysis of two accident scenarios derived from existing accident reports was conducted. Amongst other things, it was concluded that the information contained in current accident reports does not support analysis of the errors and latent conditions involved. Such features may be alluded to in the brief description of the accident, but there is no protocol for describing the errors involved. For example, although information regarding the environmental conditions involved is collected, this is only at a basic descriptor level (e.g. wet, dark etc) and no further information is provided, such as the effects of the environmental conditions on driver behaviour. Additionally, the lack of detail in the reports prevents the collection of error-related data.

In a study investigating driver error in the U.S., Wierwille et al (2002) used the results from focus groups and interviews with road transport police officers to develop a series of recommendations for improving road traffic accident report forms. One of the reasons behind this was that the data recorded on forms current at the time often lacked the precision desired by researchers (Wierwille et al, 2002). As a result of their research, Wierwille et al suggested the following recommended modifications would lead to more accurate, precise and useful crash data:

- develop a uniform coding scheme that will suit the needs of both the state and the national databases;
- make human factors improvements to existing forms and computer software;
- include principal contributing factors and driver performance errors on the form;
- eliminate re-transcription; and
- solicit officer suggestions for remedies to infrastructure and driver problems and for improvements to accident report forms.

For accident reporting and analysis to consider the errors and latent conditions involved in accidents in the road transport domain, it is apparent that the current accident reporting procedure in Victoria would need to be redeveloped. One key component missing from the data collected currently is a description of the accident from each of the road users involved. Such data could potentially contain information that would allow the accurate classification of the errors and latent failures involved. Further, as pointed out above, an error and latent failure classification scheme is also required. Such a scheme could be used either during the accident reporting procedure or during the accident analysis procedure. This would allow the collection or identification of error-specific information, including the errors and contributory factors involved in the accident in question.

The use of such an approach in the road transport domain would have to consider that the potential users of the system (i.e. police officers, road users etc) would probably not have any formal training in, or experience of, psychology and/or human factors. This would require that

the potential end users (i.e. police officers) receive training in the accident reporting approach. In particular, users would have to be familiar with the different types of latent conditions and road user errors contained in the classification schemes. It is proposed that training users in the use of an error-oriented accident reporting approach would involve introducing them to the construct of human error and error classification, describing the different latent conditions and errors with specific examples, and then conducting a series of example accident reports for a range of representative accidents. For it to be used 'on-line' during the reporting process, such an approach would have to be quick and easy to use and be fully auditable to make it a viable component of the accident reporting procedure. It is proposed that a checklist of latent conditions and road user errors would be a suitable way of ensuring that the process is simple, quick and easily auditable.

In summary, a road transport accident reporting system designed to gather error-related information in the Australian road transport system would have to:

- provide the user with a taxonomy of latent conditions (e.g. environmental, equipment etc) and errors at each organisational level within the road transport system;
- be quick and easy to use;
- be easily auditable; and
- be easily used by non-human factors/psychology professionals.

In summary, it is the opinion of the authors that the current accident reporting procedure adopted in Victoria is limited in relation to the collection of specific error-related data. As a result, analysis of the errors and latent conditions involved in road traffic accidents in Victoria is difficult, and may not be accurate. The authors recommend that the current accident reporting procedure be modified to permit the collection of specific error-related data. This might involve the inclusion of a simple checklist of road user errors and latent failures.

## **2.5 Incident or 'Near-miss' Reporting Schemes**

The widespread application, uptake and apparent success of incident or near-miss reporting systems in other transportation domains, such as aviation and rail, was highlighted in chapter 3. It is the opinion of the authors that the provision of an incident or near-miss reporting system in the road transport domain could enhance the collection of error and latent condition related data, which in turn could lead to improvements in road safety and increased error tolerance within the Australian road transport system. A number of researchers have highlighted the utility of collecting and analysing near-miss or incident data in road transport. Brown (1990) points out that most error data is derived from accident reports that are routinely collected by the police, and that we have no evidence of the majority of road user errors which result neither in personal injury nor in property damage.

Brown (1990) also points out that drivers are probably employing a range of error-correcting behaviours everyday, but because the road transport system is forgiving in the sense that other drivers may prevent an error from resulting in a collision, and also because only injury accidents are reported to the police, we know virtually nothing about the nature or importance of this behaviour; yet it is this which essentially dictates the overall safety of the transport system. Brown adds:

*“This lack of knowledge is therefore a serious omission, especially given its potential usefulness in driver training, in the design of vehicle controls, and in the design of the complex interface between the driver and the road environment” (Brown 1990).*

Ljung, Huang, Aberg & Johansson (2004) also point out that accident reports and databases cover only a limited subset of all problematic traffic scenarios (i.e. the ones reported) and that near-misses and unreported accidents contain additional information that provides a better insight into accident causation mechanisms. The success of near-miss reporting schemes in other complex, dynamic domains such as aviation (e.g. ASRS) and health care (e.g. MedWatch) indicates that such schemes in road transport may be of significance. There are a number of ways in which such a system could lead to improvements in road safety. In particular, the information collected could be used as follows:

- to gain a powerful insight into the role of error and latent conditions in incident and accident causation in the road transport system;
- to develop a comprehensive database of incidents (including near-misses) and accidents and the associated errors and contributory factors in involved;
- to provide a breakdown of the different latent conditions that reside, and the different errors that are made, within in the road transport domain;
- to provide information on road user error management strategies that are employed in response to error and latent failures within the road transport domain;
- to provide an indication of road transport system wide hazards that affect road user safety;
- to inform the development of a road transport-specific error and latent failure classification scheme;
- to inform the development of error tolerance strategies and countermeasures designed to reduce the impact and frequency of future occurrence of incidents, accidents and error within the road transport domain;
- to provide the means for qualitatively and quantitatively assessing error and incident occurrence; and
- to inform future research into error in the road transport domain.

To the knowledge of the authors, an incident or near-miss reporting system is yet to be implemented in the road transport domain. Fuller (1990) suggested a number of potential interventions for reducing the incidence of error and accidents in the road transport domain. These included the development of two anonymous, voluntary, incident reporting systems: one to gather reports of errors leading to accidents, entitled CARS (Confidential Accident Reporting System); and one to gather reports of errors leading to high risk driving incidents such as near-misses, entitled DIRS (Driver Incident Reporting System). However, to the author’s knowledge these systems were not developed and implemented.

It is therefore recommended that the development of a road transport incident reporting system be investigated further. Such a system could be used to allow road users to:

- report error-related actual and near-miss incidents in which they have been involved, including the nature of the incident and of any contributing latent conditions and errors;

- report error-related incidents which they have observed, including the nature of the incident and of any contributing latent conditions and errors;
- report errors that they have previously made or observed that potentially impacted road user safety;
- report the presence of latent conditions in the road transport system;
- report any error management strategies employed in the event of errors and latent conditions encountered; and
- report safety concerns regarding the road transport system.

In line with incident reporting systems used in other domains, it is recommended that a road transport incident reporting system be anonymous and non-punitive. The proposed scheme could potentially involve the use of a website, a telephone line, or a postal system in which road users could anonymously and confidentially report the types of incidents described above. The scheme would provide road users with an appropriate incident reporting form with which to report the incident. Potentially, an incident reporting form designed to gather the following information could potentially be used to collect pertinent error data:

- road user demographics (e.g. age, sex, driving experience);
- type of vehicles involved;
- incident description;
- incident diagram (where appropriate);
- road user errors involved (using a road user error classification scheme);
- latent conditions involved (using a latent condition classification scheme);
- environmental conditions;
- time of day; and
- location.

In order for the data reported to adequately describe the latent conditions and errors involved in incidents, it is also recommended that the reporting form uses an error and latent condition classification system like the proposed error and latent failure classification scheme described in section 2.3.

## **2.6 Observational study, Questionnaires and Interviews**

The merits and disadvantages of observational study, questionnaires and interviews for the collection of error-related data in the road transport domain have been discussed above. Despite their flaws, it is concluded that observational study coupled with questionnaires and interviews is an attractive and viable way of collecting such information. Observational study, questionnaires and interviews have been used extensively in the past to collect crash-related data, and offer a simple and effective means of collecting road transport data. It is therefore recommended that observational study, such as on-site surveillance, coupled with road user interviews or questionnaires be used to gather error-related information in the road transport domain.

## 2.7 Human Error Identification

The prediction of human error has been used extensively in other complex sociotechnical systems. HEI techniques are extremely flexible and can predict or highlight error at any stage of a system's life-cycle: an early design concept, for example, or an existing, operational system. However, to the authors' knowledge, a road transport specific HEI approach is yet to be developed and applied. This is surprising, particularly when considering the previously estimated role of human error in road traffic accidents.

The literature also indicates that in most complex, sociotechnical systems specific HEI techniques have been developed and applied consistently. For example, the Systematic Human Error Reduction and Prediction Approach (SHERPA; Embrey, 1986) was developed for the nuclear reprocessing domain, the Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACER; Shorrock and Kirwan, 2002) was developed for the air traffic control domain, and the Human Error Template (HET; Marshall, et al 2003) was developed for the civil aviation domain. The authors acknowledge that this may be due to the nature of the road transport system, in that it is an open, rather than a closed system, and that error may be more difficult to accurately predict in open systems. However, error prediction has previously been used successfully to predict errors resulting from man-machine interactions taking place in open systems. For example, Baber & Stanton (1996) reported that the predictions derived from two HEI approaches for a ticket vending machine task compared favourably with the errors observed in actual ticket vending machine use, and Stanton & Stevenage (1999) reported the successful use of the SHERPA technique in predicting errors arising from a confectionary vending machine task. It is our opinion that such evidence implies that error prediction in road transport is a viable concept to pursue. The authors argue that HEI techniques could be applied in a number of areas in the road transport, including:

- the prediction of latent conditions and driver errors. This information could then be used to inform the development of error tolerance strategies and countermeasures designed to mitigate and/or eradicate such errors;
- the evaluation of new technologies and concepts within the road transport domain. A road transport specific HEI technique could be used to predict potential errors that might arise from driver interaction with novel technologies and interfaces, such as new ITS technology, and in-car entertainment;
- the evaluation of proposed infrastructure developments. A road transport specific HEI technique could be used to determine road user errors that might arise from the introduction of new road furniture or infrastructure, such as novel road signage, variable messaging systems and novel road layouts; and
- the evaluation of vehicle cockpits. A road transport specific HEI technique could be used to predict potential errors that might arise as a result of the interaction between a driver and a novel vehicle cockpit design.

To demonstrate the potential application of a HEI technique in the road transport domain, an example application using the SHERPA approach was conducted. The analysis involved predicting driver errors for an intersection scenario. A HTA was conducted for the intersection scenario based upon an original HTA of the driving task that was developed by Walker (2002). An extract of the 'negotiate intersection' HTA is presented in Figure 2.7. An extract of the SHERPA analysis is presented in Table 2.7.

0. Efficiently & Safely negotiate cross Intersection

Plan 0. Do 1, then 2 or 3 or 4 as appropriate

1. Prepare to negotiate intersection

Plan 1. Do 1.1 and 1.2 and 1.3

1.1. Approach intersection

Plan 1.1. Do 1.1.1 and 1.1.2 and 1.1.3

1.1.1. Maintain course

1.1.2. Maintain appropriate speed

1.1.3. Maintain appropriate vehicle control

1.2. Make pre-liminary intersection checks

Plan 1.2. Do 1.2.1 and 1.2.2 and 1.2.3 and 1.2.4 as appropriate

1.2.1. Check road signage

1.2.2. Check traffic light signals

1.2.3. Observe other traffic

Plan 1.2.3. Do 1.2.3.1 and 1.2.3.2 and 1.2.3.3 and 1.2.3.4 and 1.2.3.4 and 1.2.3.5 and 1.2.3.6 and 1.2.3.7

1.2.3.1. Observe traffic ahead

1.2.3.2. Observe offside traffic

1.2.3.3. Observe nearside traffic

1.2.3.4. Observe traffic to the rear

1.2.3.5. Observe oncoming traffic

1.2.3.6. Observe cross traffic

1.2.3.7. Check for additional hazards

1.2.4. Check for other road users

Figure 2.5. Extract of HTA for intersection scenario.

Table 2.7 Extract of SHERPA analysis for intersection scenario

Task Step	Error Mode	Error Description	Consequence	Recovery	P	C	Remedial Strategy
1.1.1.	A8	Fail to maintain appropriate course	Vehicle drifts into wrong lane	Immediate	M	M	- Lane keeping system - Rumble strips/Raised road markings
1.1.2.	A8	Fail to maintain appropriate speed	Vehicle may be travelling too fast or too slow for intersection	Immediate	M	M	- Slow down/Break now road signage - In-vehicle speed warning system - Intelligent braking system
1.2.1.	C1	Fail to check road signage	Driver does not comprehend which routes are available and which is the correct route to take	1.3.1/1.3.2/1.3.3	H	M	- Increased road signage conspicuity - In-car navigation system
1.2.1.	C3	Driver checks the wrong road sign	Driver does not comprehend which routes are available and which is the correct route to take	1.3.1/1.3.2/1.3.3	L	M	- Reduction in distracting/inappropriate road signage (e.g. advertising) - Increased road signage conspicuity
1.2.1.	C4	Misread road signage	Driver moves into the wrong lane and takes the wrong route	1.3.1/1.3.2/1.3.3	M	M	- Clearer road signage
1.2.2.	C1	Fail to check traffic lights	Driver does not comprehend the current signal and may pass through red light	Immediate	M	H	- Increased traffic light conspicuity - Intelligent in-vehicle traffic signal alert system
1.2.2.	C4	Misread traffic signal	Driver does not comprehend the current signal and may pass through red light or stop at green light	Immediate	M	H	- Increased traffic light conspicuity - Intelligent in-vehicle traffic signal alert system
1.2.3.1.	A8	Fail to observe traffic ahead	Driver does not see vehicle in front slowing down and could hit vehicle	Immediate	M	H	- Reduction in in-vehicle distraction
1.2.3.2.	A8	Fail to observe offside traffic	Driver does not comprehend presence and location of offside traffic	Immediate	H	H	- In-vehicle road user positioning display
1.2.3.3.	A8	Fail to observe nearside traffic	Driver does not comprehend presence and location of nearside traffic	Immediate	H	H	- In-vehicle road user positioning display
1.2.3.4.	A8	Fail to observe traffic to the rear	Driver does not comprehend presence and location of traffic to the rear	Immediate	H	H	- In-vehicle road user positioning display
1.2.3.5.	A8	Fail to observe oncoming traffic	Driver does not comprehend presence and location of oncoming traffic	Immediate	H	H	- In-vehicle road user positioning display
1.2.3.6.	A8	Fail to observe cross traffic	Driver does not comprehend presence and location of cross traffic	Immediate	H	H	- In-vehicle road user positioning display
1.2.3.7.	C1	Fail to check for additional hazards	Driver does not comprehend presence of additional hazards	Immediate	H	H	- In-vehicle road user positioning display
1.2.4.	C1	Fail to check for other road users	Driver does not comprehend presence and location of other road users	Immediate	H	H	- Increased road user conspicuity - In-vehicle road user positioning display

As with the other potential human error-related applications described previously in this section, the validation of a road transport specific HEI technique and the errors predicted by analysts using the technique requires specific data regarding the nature of errors and latent conditions that currently exist within the road transport domain. This data can then be used to validate the HEI approach and the errors predicted by analysts using it.

## **2.8 Error Tolerance Strategies Within The Australian Road Transport System**

The ultimate goal of any error management framework in the road transport domain is the development of an error-tolerant road transport system. Rather than attempt to eradicate errors, we must accept that errors do, and will always occur, at each of the different organisational and actor levels within the road transport system. The key to an error-tolerant system is to develop and implement strategies and measures designed to enhance error tolerance within the road transport system. It has been demonstrated throughout this report that the development of error tolerance strategies is dependent upon the collection of error-related data. According to Fuller (2002), analysing human error can provide guidance on how to increase system tolerance by identifying where errors are likely to occur and their likely impact. Using the error data collected and identified by the methods and programs described previously in this chapter, specific strategies and countermeasures should be designed and implemented. The authors propose the utilization of the following categories of error and tolerance strategies within the road transport system:

- training;
- error management technique;
- road infrastructure design;
- vehicle design;
- policy, regulations and legislation; and
- advertising campaigns.

A brief discussion of potential error mitigation and tolerance strategies within each category is presented below. The authors wish to point out that the exact nature of the error tolerance strategies is not yet clear, since this will be determined once sufficient error data collection and analysis has been conducted within the Australian road transport domain. It is proposed that the error-related data collected and analysed within the first three layers of the framework be used to inform the design and development of the error tolerance strategies discussed below.

### **Training**

One way of managing or mitigating error and promoting error tolerance in safety critical domains is through the provision of training. For example, 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. CRM error management training is based on the idea that error is inevitable and training is provided in recognizing the limits of human performance and managing errors as they arise (Helmreich, Wilhelm, Klinect, & Merritt, 2001). Such training programs emphasise how errors can be mitigated or managed through preparation, planning, checking, vigilance, decision making strategies and task prioritisation. It is the opinion of the authors that a driving-specific error management training program could significantly enhance error tolerance within the road transport domain.

According to Thomas and Petrelli (2004) error management training refers to the structured development of error management skills in the training environment. Thomas and Petrelli (2004) used interviews with experienced aviators in order to investigate what exactly the core components of effective error management within the commercial aviation domain were. They concluded that error management training comprises three phases, error avoidance, error detection, and error response. Error avoidance involves attempting to avoid error occurrence through the use of a wide range of techniques. Error detection involves detecting errors as they

arise, and depends to a large extent on the maintenance of situation awareness. Error response involves the rectification of error, or the resolution of any problem-state that is caused by an error. In conclusion, Thomas and Petrelli (2004) proposed a generic structure for the debrief of error events in error management training that includes the following sequences:

- the causes of the error and the error producing conditions that were present;
- the strategies that were used to avoid the error and what could be done better;
- the strategies that were used to detect the error and what could be done better;
- the consequences of the error and technical options available to resolve the error; and
- the strategies that were used to resolve the error and what could be done better.

Despite being developed within the civil aviation domain, CRM training programs have 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 reduce 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. In particular, Mitsopoulos et al reported that the main emphasis of young driver CRM training should be upon the communication skills required to achieve the following three critical tasks:

- ensuring the driver is fit to drive;
- ensuring the driver drives safely; and
- ensuring hazards are detected and appropriate action is taken.

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 and passengers 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.

Such a program would aim to develop road user (driver, passenger) competencies for avoiding errors and for managing errors and latent conditions as they arise. The exact content of a driver error management training program remains unclear, and further exploration is required in order to specify road user error management strategies. Potentially road users and passengers could be given training in the communication and technical skills required for error management. This might involve training passengers in the skills required to monitor for driver errors and also in the skills required to communicate their concerns to the driver if they detect an error or in the event of a road user error of some sort (e.g. watch out for the red car as he is travelling too fast and too close to the car in front). Additionally, drivers could be given training in the skills required for error recovery purposes. It is recommended that the development and provision of error management training should be investigated within road transport. Error management training could potentially be implemented either as part of existing driver training programs or as a stand-alone course. As a starting point, the authors recommend that driver training programs should at least introduce the concept of driver error and its management. It is recommended that a driver training error management component should emphasise the following:

- road user error is an inevitable feature of activity within the road transport system;
- road user error is a consequence of latent conditions residing within the road transport system;
- road user errors and their effects can be avoided or at least reduced through the effective use of error management strategies, including error detection strategies, error avoidance strategies and error response strategies; and
- in those instances where road user errors occur, error management strategies can be used to mitigate or tolerate the consequences arising from the errors made.

The application of error management training within driver training programs should be explored further. In particular, the content of error management training programs from other domains should be analysed for its applicability in the road transport domain, and potential error management strategies for drivers should also be investigated. It is recommended that appropriate road user error management strategies be developed and taught in such programs. As with most of the other error-related applications described in this chapter, the identification, development and teaching of road user error management strategies is dependent upon the collection and analysis of error-related data within the road transport domain.

## **Error Management Technique**

Structured error management techniques have been applied with some success in other complex sociotechnical systems. For example, the TRIPOD DELTA approach has been used in the oil exploration and production domain, and the REVIEW approach has been used in the rail transport domain. It is the opinion of the authors that the provision of an error management technique similar to the TRIPOD DELTA and REVIEW approaches would be of considerable utility within the road transport domain as it could be used to highlight those latent conditions that represent a significant threat to performance and safety at different sites within the road transport system. A taxonomy of latent conditions could be used in conjunction with a rating

system to highlight conditions that represent a significant threat to road user safety and performance. On the basis of this, appropriate remedial measures could then be proposed and taken. This would allow the systematic removal of error causing or latent conditions at different sites throughout the road transport system.

Taking intersections as an example, such an approach could be used to identify those latent conditions that represent a significant problem at different intersections. When using TRIPOD DELTA and REVIEW, safety managers with domain expertise use taxonomies of latent conditions and rate the extent to which each of the latent conditions represent a problem in the system in question. With regard to road transport, such an approach would comprise a taxonomy of road transport specific latent conditions which would be rated by appropriate SMEs in terms of the extent to which they were problematic at particular intersection sites. For example, if visibility of a traffic device was obscured by other road signage at a particular intersection site, this would be rated as highly problematic, and appropriate measures would be recommended in order to remove the problem. The results could pinpoint features of a particular intersection that contribute to road user error, and could inform the development of measures or strategies to remove the latent conditions identified.

The authors therefore recommend that the development of a specific road transport error management approach be investigated further. It is proposed that such an approach will be developed on the basis of the results derived from the Phase 3 and 4 pilot study, and would include a taxonomy of latent conditions or road transport contributing conditions.

## **Road Infrastructure Design**

One way of reducing the latent conditions and promoting error tolerance within the road transport domain is through the appropriate design of road infrastructure. In conclusion to their study on driver error in the U.S, Wierwille et al (2002) point out that it should be the goal of the highway and traffic engineers to reduce the likelihood of, or eliminate, 'infrastructure' as a contributing factor in road traffic crashes, and that drivers should not be forced to make unsafe manoeuvres by infrastructure. Wierwille et al also recommend that engineers should strive to make the driving environment as forgiving as possible so that crash likelihood and severity are minimised.

## **Vehicle Design**

As with road infrastructure design, appropriate vehicle design offers another avenue for mitigating error and for promoting error tolerance. Within road transport, vehicles represent the equipment that drivers use to achieve their task of traveling from A to B. Designing to reduce error is a common approach and involves the application of HEI. Designing systems to be tolerant of user error is also an accepted approach that is adopted in the design of most systems. However, the extent to which these principles are adopted during the design of vehicle cockpits and in-vehicle systems is currently not known. It is therefore recommended that guidelines or recommendations for error reduction and error tolerance within vehicles be developed. For example, Norman (2001) suggests that two design lessons can be drawn from the study of slip type errors, one for preventing slips before they occur and one for detecting and correcting slips when they do occur. Norman (2001) proposes that designers should:

1. Understand the causes of error and design to minimise those errors;
2. Make it possible to reverse or undo actions – or make it harder to do what cannot be undone;
3. Make it easier to discover the errors that do occur, and make them easier to correct; and
4. Change the attitude towards errors.

One way in which designers attempt to reduce error occurrence is through the use of forcing functions or physical constraints. Norman (2001) cites the example of locking one's keys in the car. Car designers now design car doors so that they cannot be locked without the key. Thus, the driver is forced to have the keys in order to lock the door. This type of design is known as a forcing function.

## **Policy, Regulation and Legislation**

Road transport policy, regulation and legislation can also be used to promote error tolerance within the Australian road transport system. Based upon the findings from the preceding three layers of the framework, targeted policy, regulation and legislation can be developed with the aim of enhancing error tolerance.

## **Advertising campaigns**

The road transport domain is unique in that it is an open as opposed to a closed system, and the road users using the system typically only receive training once. There is also no requirement for maintenance of skills and re-training. One approach used to inform road users of safety concerns, strategies and behaviour related countermeasures is through the use of targeted advertising campaigns. One way of promoting error tolerance would be through the use of advertising campaigns. Such campaigns could be used to convey error management strategy-related information to road users, such as drivers and pedestrians. It is therefore recommended that the use of advertising campaigns in promoting error tolerance throughout the Australian road transport system be investigated further, particularly with regards to the content and delivery of such campaigns.

## **2.9 Human Error Workshop**

A workshop was held on June 23<sup>rd</sup> at MUARC in order to present the findings derived from the research conducted to that point and also the proposed framework for error tolerant intersections and an error tolerant road transport system. Present were members with appropriate expertise from the road transport and other relevant research communities, including representatives from VicRoads, the Transport Accident Commission (TAC), the ATSB, Victoria Police, Dédale Asia-Pacific and MUARC. The aims of the workshop were to gain input on the following three issues:

- the findings derived from the research conducted during phase 1 of the research program;
- the proposed framework for error tolerance; and
- the methodology for conducted a pilot study on error and latent conditions within the Australian road transport domain.

The feedback on the findings from the Phase 1 literature review were positive, and all participants agreed that there is great scope for conducting further research into human error within a road transport context. With regard to the proposed framework for error tolerance and the Phase 3 pilot study, the methods with which the error data would be collected and analysed were subject to great discussion. The general consensus was that the methods to be used for this purpose should be well developed and validated, and that the kind of data that is required should be clearly defined prior to any data collection effort. A number of further avenues for collecting human error data in road transport were discussed, including a modified police accident reporting form and the analysis of existing in-depth crash databases (e.g. ANCIS). It was also concluded that incident reporting may be too difficult to implement within the road transport system.

The open (as opposed to closed) nature of the road transport system was also discussed, and it was concluded that, although the variability in behaviour and lack of enforcement of road user participation would make the implementation of the framework more difficult, it would not make it impossible nor unworthy. The general consensus between workshop participants was that the similarities between open and closed systems meant that studying and attempting to manage error within road transport was a viable concept.

The reasons why error management has previously received only minimal attention were also discussed. These included the open nature of the road transport system, the previous focus on attempting to prevent violations rather than errors, and also the difficulties associated with collecting error data within the road transport system. Despite the various difficulties discussed, it was agreed that this should not deter future research effort in the area.

In relation to the pilot study on error and latent conditions within the road transport system that is to be designed and conducted during Phases 3 and 4 of this research program, the following conclusions were made:

- due to the size and complexity of the road transport system in Australia, it may be more useful to focus the finite project resources initially on error at intersections only rather than error in the road transport system as a whole. This would allow the framework to be tested and refined in a more controllable and manageable environment before it is implemented system-wide; and
- the methodology that is employed to collect the error data is especially important with regard to the quality of the data that is gathered and to the subsequent error management strategies used. Therefore the data collection procedure employed needs to be clearly defined prior to the conduct of an error study.

In summary, the workshop was useful in that it facilitated discussion surrounding the topic of human error and road transport, and also allowed the authors to gather constructive feedback on the proposed framework for error tolerance. In particular, a focus on error and latent conditions at intersections rather than in the whole road transport system was decided on as a result of the workshop, and the need to refine the methodology for collecting error data was noted.

## 2.10 Summary

Based upon the literature review conducted during phase 1 of this research program, a conceptual framework for error-tolerant intersections and an error-tolerant road transport system in Australia was presented in this chapter. It is the opinion of the authors that the implementation of the framework could lead to enhanced error tolerance within the Australian road transport system. It is also intended that the framework presented in this chapter form the basis of a pilot study to collect data on error and latent conditions at intersections. The pilot study protocol will define the methods to be used for collecting this human error data, for classifying the data collected, for analysing the data in a manner which informs the development of countermeasures for preventing accidents and incidents attributable to human error in the road transport domain, and for enhancing error tolerance at intersections and within the road transport system in general. An action plan, for implementing the study protocol, will also be developed. While the precise methodology to be employed is yet to be determined, it is likely that it will involve the collection of human error data using a combination of the different methods described in the framework. The findings from the pilot study will provide important insights into the role of human error in accidents and incidents in road transport in Australia, will provide suggestions for the improvement of data collection and analysis methods, and will form the basis for the development of an ongoing error management program in Australia that addresses the role of human error in road crashes.



## Chapter 3 Conclusions

### 3.1 Summary

The purpose of this phase of the research program was to develop a conceptual framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole. This involved identifying potential human error-related applications, developed and applied in other domains, that could be used in the road transport domain as part of an error management program. On the basis of this, and the work conducted during the first phase of this research program, a conceptual framework for error tolerant intersections in Victoria and throughout the Australian road transport system as a whole was proposed. The framework contains both the methods with which to collect and analyse error-related data and also a number of error management approaches designed to reduce, eradicate or manage road user error and its contributory conditions. It is recommended that error management strategies are then developed on the basis of the analysis of human error-related data. The framework was proposed as a way of increasing our understanding of road user error and enhancing error tolerance at intersections and in the general road transport system. The framework is novel as it attempts to make error-data collection, error management and error tolerance strategy development standard components of the overall working system, rather than part of reactive error-related studies. The proposed framework contains the following human error-related applications:

- application of existing human error theory in the road transport domain;
- collection of error-related data at specific road sites;
- development of a human factors oriented road transport accident reporting tool;
- development of a road transport incident or near-miss reporting system;
- development of a road user error classification scheme;
- development of a road system latent condition classification scheme;
- development of road user error and latent condition databases;
- development of a valid human error identification technique for the road transport domain;
- development of a road transport-specific error management technique (i.e. a latent conditions rating and assessment tool, similar to the REVIEW and TRIPOD DELTA approaches used in the rail and oil exploration and production domains);
- development of error tolerance strategies (e.g. infrastructure and in-car technology design) and policies (e.g. legislation and advertising campaigns) designed to increase error tolerance and/or mitigate error and its consequences within the road transport domain; and
- development of error management driver training interventions.

It is the opinion of the authors that the implementation of such a framework could form the first steps in the development of error-tolerant intersections and an error-tolerant road transport

system in Australia, and could in turn enhance road user safety considerably. It is also intended that the methods required for the error pilot study that is to be designed and conducted during the next phases of this research program are extracted from the framework.

To demonstrate the potential of such a framework, each component application was investigated with regard to its potential application in the Australian road transport system. Firstly, the systems perspective approach to human error and accident causation proposed by Reason (1990) was related to the Australian road transport system and used to analyse a series of road traffic crash scenarios. The results indicate that the systems perspective is useful for analysing incidents and accidents in a road transport context. Additionally, it was concluded that the development of a road transport-specific error accident investigation approach, similar to the HFACS approach used in aviation, be investigated further.

Secondly, the concept of error classification within the road transport domain was discussed. It was recommended that road user error and road transport system latent condition classification schemes be developed, based on information derived from existing error classification schemes and error taxonomies (e.g. HFACS, DREAM), accident reports, information derived from the analysis of road traffic accidents (using data from accident databases), information collected from a road transport incident or near-miss reporting system, information collected from on-site and in-car observational study, and information from road user interviews and questionnaires. To investigate further, a prototype model of road user error was developed and prototype road user error and latent condition classification schemes were proposed. It is intended that the prototype classification schemes are used to classify the error data that is gathered during the conduct of the phase 3 and 4 error pilot study.

Thirdly, the concept of accident reporting and investigation in the road transport domain was investigated. It was concluded that the current approach in Victoria is inadequate for error and latent condition analysis purposes. In particular, that the level of detail contained and type of information collected inhibit the analysis of the errors and latent conditions involved in accidents. It was therefore recommended that a novel approach to accident reporting and analysis be developed. It is apparent that for accident reporting and investigation in road transport to provide sufficient information to permit the analysis of the latent conditions and errors involved in accidents, some sort of road transport error and latent condition taxonomy or classification scheme is required, similar to the HFACS approach. This would allow the collection of specific error data, including the errors and contributory factors involved in accidents.

Fourthly, the potential use of incident or near-miss reporting schemes within the road transport domain was investigated. The potential utility of such an approach within the road transport domain led the authors to conclude that the development and application of a road transport incident reporting system be investigated further. The exact nature of such an approach remains unclear at present, but could involve a website, telephone line or postal system that is non-punitive and confidential. Additionally, the authors recommend that such a system should allow road users and transport professionals to report actual and near-miss incidents in which they have been involved, report near-miss incidents which they have observed, and report safety concerns regarding the road transport system.

Fifthly, the potential use of observational study, questionnaires and road user interviews for the collection of error-related data was discussed. It was concluded that these traditional data collection procedures offer a viable means for collecting human error-related data within road

transport. However, a number of disadvantages were identified that could significantly impact the quality of the data. These include a lack of experimental control, a limit to the information that can be derived from such data (for example, it may be impossible to derive why errors occurred and to identify the latent failures involved in their occurrence) and the expense and time involved in analysing the data.

Sixthly, the concept of Human Error Identification (HEI) in road transport was investigated. To investigate the potential application of HEI techniques within road transport, an exploratory Systematic Human Error Reduction and Prediction Approach (SHERPA) analysis of an intersection HTA was conducted. The results indicate that error prediction in road transport is an appropriate concept to pursue. It was therefore recommended that a road transport-specific HEI technique be developed.

Finally, the application of error management training within the road transport domain was discussed. In conclusion it was recommended that the concept of error management training within the road transport domain be investigated further.

The final part of this stage involved discussing the potential error tolerance strategies that might arise from the human error related applications described above. The authors propose that potential error tolerance strategies in road transport can be broadly categorised into the following groups:

- training;
- error management technique;
- road infrastructure design;
- vehicle design;
- policy, regulations and legislation; and
- advertising campaigns.

To gather feedback on, and to refine the proposed error tolerance framework, a workshop was convened by MUARC. The workshop involved a number of project stakeholders and also Subject Matter Experts (SMEs) from the road transport and other relevant domains in which error management approaches have previously been implemented. Workshop participants were given a presentation detailing the findings from the first phase of the research program and an outline of a proposed framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole. Several key conclusions derived from the workshop included:

- due to the size and complexity of the road transport system in Australia, it may be more useful to focus the finite project resources on error at intersections only rather than on error in the road transport system as a whole. This would allow the framework to be tested and refined in a more controllable and manageable environment before it is implemented system-wide;
- the methodology that is employed to collect the error data is particularly important with regard to the quality of the data that is gathered and to the subsequent error management strategies that are developed. Therefore the data collection procedure employed needs to be clearly defined prior to the conduct of an error study;

- the road transport system is an ‘open’ system with lots of variation in terms of behaviour and vehicle condition, standard and capability. Historically, error management programs have been implemented in ‘closed’ systems. However, the open nature of the road transport system should not inhibit the use of error management programs or the conduct of further error-related research;
- there are a number of reasons why error management has not been employed within road transport to date. These include the open nature of the road transport system, the previous focus on attempting to prevent violations rather than errors, and also the difficulties associated with collecting error data within the road transport system;
- it may be useful to use a modified accident reporting form, at least during the duration of the Phase 3 pilot study, to allow the police to collect error-related data during accident reporting; and
- incident reporting may be too difficult to implement within the road transport system.

## **3.2 Conclusion**

The research conducted during the previous phase of this research program demonstrated, among other things, that there is currently a lack of knowledge regarding human error and latent conditions in the Australian road transport system. Further, the means (e.g. error data collection techniques) with which to collect the error-related data required to enhance our understanding of error and latent conditions is lacking. In response to this, a conceptual framework for promoting error tolerance at intersections in Victoria and throughout the Australian road transport system as a whole was proposed. The framework comprises a series of methods for the collection and analysis of error-related data, and a number of potential error tolerance strategies. Each component of the framework was investigated with regard to its potential application within road transport. In conclusion, it is our opinion that these exploratory applications demonstrate that there is significant potential for applying the framework within the Australian road transport system, and that the development and application of error management programs within road transport is a viable concept to pursue. It is recommended that the framework be used to inform the development of the methodology for the error pilot study that is to be designed and conducted during the next phase of this research program.

## **3.3 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 into the construct of human error within the road transport domain, particularly with regards to the collection of human error-related data and the development and application of error management approaches. The authors propose that the following areas be investigated further:

- To investigate human error and latent conditions in the Australian road transport domain, it is proposed that a pilot study be designed and conducted to collect data on errors and latent conditions at intersections. The design and conduct of such a study forms the next phase of this research, and it is proposed that a number of the methods presented in the framework for

an error tolerant road transport system will be used to collect and analyse specific data on latent conditions at selected intersection sites;

- Re-iteration and validation of the prototype road user error and latent condition classification schemes. The authors acknowledge that the prototype road user error and latent condition classification schemes presented in this report are limited in that they were developed in the absence of data on road user errors and latent conditions from the Australian road transport system. It is therefore recommended that the classifications schemes are further re-iterated and refined on the basis of the results of the pilot study referred to above;
- Development of a novel approach to road transport accident reporting and analysis. The research conducted to date indicates that the current approach to accident reporting and analysis in Victoria is inadequate for the comprehensive analysis of the errors and latent conditions involved in road traffic accidents. The authors therefore recommend that a novel approach to accident reporting and analysis be developed that considers such factors. It is proposed that such an approach would be based upon the error and latent condition taxonomies described above. Once the scheme is developed, the authors recommend that it be trialed by Victoria Police;
- Development of a road transport-specific incident or near-miss reporting system. The utility of incident and near-miss reporting schemes employed in other domains was highlighted during this research. The authors recommend that a pilot incident reporting scheme be developed trialed and implemented within the road transport domain. It is proposed that such a scheme will contribute to the development of a database of road user error and latent conditions residing within the road transport system;
- Development of a road transport-specific HEI technique. The utility of HEI in other complex, dynamic domains was highlighted in this report. The authors recommend that a road transport-specific HEI technique be developed. It is the opinion of the authors that such an approach could potentially be used to evaluate new road transport technology (e.g. ITS, vehicle cockpit designs), and novel road infrastructure designs. It is proposed that the road transport HEI technique uses the taxonomies of road user error and latent conditions described above;
- Investigation and development of error management training interventions. The concept of error management training was introduced in this report. The authors recommend that the provision of error management training within the road transport be explored further. In particular the content, delivery and potential impacts of such programs should be investigated;
- Development of a road transport-specific error management technique. It is the opinion of the authors that the provision of an error management technique similar to the TRIPOD Delta and REVIEW approaches used in oil exploration and production and rail transport would be of considerable utility within the road transport domain. It is therefore recommended that a trial intersection error management approach be developed. Such an approach could be used to identify those conditions that represent a significant problem (i.e. they have the potential to negatively impact road user safety) at different intersections;
- Development and implementation of strategies designed to increase error tolerance at intersections and within the Australian road transport domain in general. The authors recommend that targeted strategies designed to increase error tolerance at intersections and in the Australian road transport system should be developed and implemented. This might

include novel training interventions, novel vehicle and in-car technology design, road infrastructure and furniture design, legislation and regulations and advertising campaigns; and

- The conduct of further error-related research within road transport. In general, the construct of human error remains largely unexplored within the Australian road transport system. The authors recommend that further study be conducted in the area of road user error. There are a number of potential areas for future research, including the impact of intelligent transport system (ITS) technology on road user error, the differences in the errors that are made by different road user groups (e.g. elderly, novice, impaired etc) and the design of vehicles and road infrastructure to tolerate road user errors.

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