A Systems Perspective on Road User Error in Australia: Swiss cheese and the road transport system

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ABSTRACT

Within complex socio-technical systems human error has consistently been implicated as the major causal factor in a high proportion of accidents and safety compromising 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 article describes the work conducted to date as part of a research program of which the main 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 research conducted to date and of the error management techniques that have previously been employed in complex sociotechnical systems, a conceptual framework for an error tolerant Australian road transport system is proposed. The proposed framework contains appropriate methods for the collection and analysis of human error-related data within the Australian road transport system, and 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 the opinion of the authors that the implementation of the framework will considerably increase our knowledge of road user error and the conditions that cause it, and could potentially enhance error tolerance and road user safety within the Australian road transport system.

Keywords: Human error, systems perspective, error tolerant road transport system.

INTRODUCTION

Human error is a complex phenomenon and is a great concern to safety professionals within complex sociotechnical systems. Within such systems, human error has historically been implicated as a contributory factor in a high proportion of accidents and incidents. For example, in domains such as civil aviation, rail and healthcare, human error has been identified as the source of anywhere between 70% and 95% of accidents and incidents. Road transport is no different, and recent research 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). Consequently, the construct has been emphatically investigated in a wide range of domains, culminating in the development of error management programs and methods designed to remove, reduce or manage error and the conditions that lead to it.

Despite being identified as a major problem within road transport, there has only been a paucity of human error-related research conducted in road transport to date. In addition, the use of error management methods has been neglected, and consequently very little is currently known regarding the nature of road user errors and of the contributory factors and consequences associated with these errors. This article describes the findings derived from the first two phases of a research program, the aim of which is to promote error tolerance within the Australian road transport system. The research conducted to date included a review of the human error-related research conducted to date in other domains and in road transport; a review of the current approaches to human error management in complex sociotechnical systems; and the development of a conceptual framework for an error tolerant Australian road transport system.

THEORETICAL PERSPECTIVES ON HUMAN ERROR

The complexity of the construct is such that there have been numerous attempts at defining human error. Despite this, a universally accepted definition of human error is yet to emerge. Of the definitions presented in the literature, those proposed by Senders and Moray (1991) and Reason (1990) are the most widely acknowledged and appropriate. Senders and Moray (1991) suggested that error is something that has been done which was either: not intended by the actor; not desired by a set of rules or an external observer; or that led the task or system outside of its acceptable limits. Reason (1990) defines human error as, "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency." Within the literature, two theoretical perspectives currently dominate: the *person* and the *systems perspective* approaches.

The Person Approach

The person approach focuses upon the identification and classification of the errors that operators make at the so-called 'sharp-end' of system operation (Reason, 2000) and seeks to identify the internal or psychological factors involved in error occurrence. According to the person approach errors arise from aberrant mental processes such as forgetfulness, invigilance, inattention, poor motivation, carelessness, negligence, and recklessness (Reason, 2000). When using the person approach, human error is treated as the cause of most accidents; the systems in which people work are assumed to be safe; human unreliability is seen as the main threat to system safety; and safety progress is achieved by protecting systems from human unreliability through automation, training, discipline, selection and proceduralisation (Dekker, 2002). A number of different person-based models of human error have been proposed, including the skill, rule and knowledge-based framework (SRK; Rasmussen, 1983; cited in Vicente, 1999), the generic error modelling system (GEMS; Reason, 1990) and Rasmussen's model of human malfunction (Rasmussen, 1982).

The Systems Perspective Approach

The systems perspective approach treats error as a systems failure, rather than an individual operator's failure and considers the combined role of latent or error causing conditions (e.g. inadequate equipment and training, poor designs, inadequate supervision, manufacturing defects, maintenance failures, ill-defined procedures etc) and human errors in accident causation. Human error is seen to be a consequence of the latent conditions residing within the system. Therefore, when using the systems approach, human error is treated as a symptom of problems within the system; it is assumed that safety is not inherent within systems; and that human error is linked to the tools used, tasks performed and operating environment (Dekker, 2002).

The systems perspective model of human error and accident causation proposed by Reason (1990) is the most influential and widely recognised of the error models presented in the literature. The Swiss cheese model (as it is more commonly referred to due to its resemblance to a series of layers of Swiss cheese) considers the interaction between latent conditions and errors and their contribution to organisational accidents. According to the model, systems comprise various organisational levels that contribute to the production of system outputs (e.g. decision makers, line management, productive activities and defences). Each of the levels has various defences in place that are designed to prevent accidents and safety compromising incidents. Examples of defences include protective equipment, rules and regulations, training, checklists and engineered safety features. Holes or weaknesses in the defences created by latent conditions and errors create ‘windows of opportunity’ for accident trajectories to breach the defences and cause an accident. Accidents occur when the holes line up in a way that allows the accident trajectory to breach each of the different defences that are in place. On most occasions, accident trajectories are halted by defences at the various levels in the system. However, on rare occasions, the holes or windows of opportunity line up to allow the accident trajectory to breach all of the defences, culminating in an accident or safety-compromising incident. The Swiss cheese model is presented in figure 1.

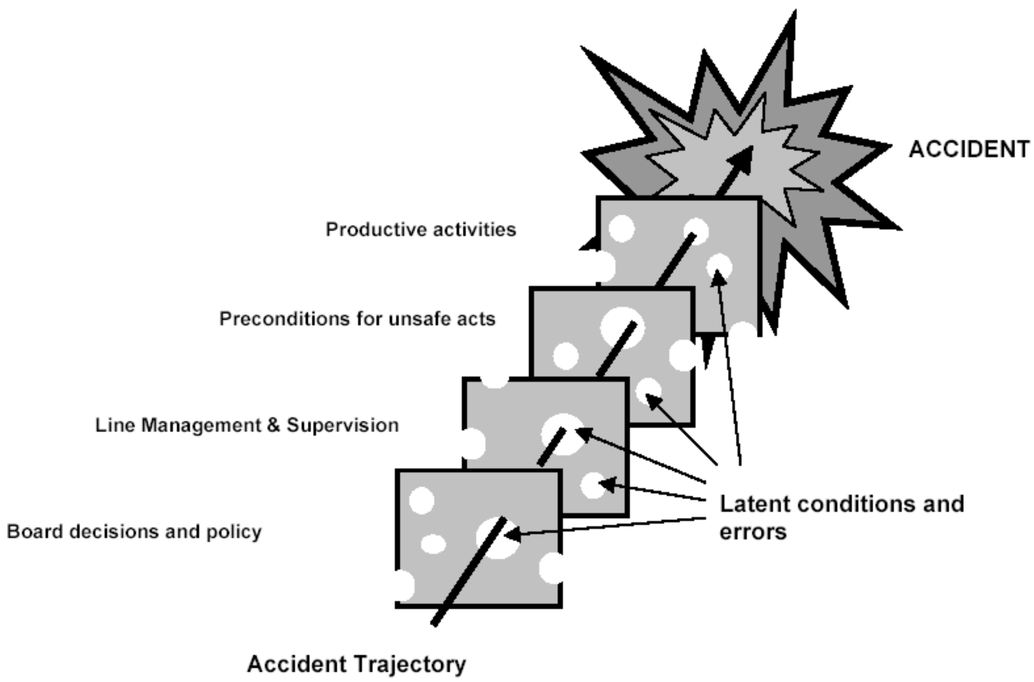

Figure 1. Swiss cheese model of error and accident causation

The Swiss cheese model is particularly useful for error and safety management in organizational systems. The model is a simplistic, intuitive approach to human error and provides a useful insight into the interaction between latent conditions and errors within complex sociotechnical systems and their role in accident causation. The model's simplicity allows it to be applied by practitioners with little or no experience of psychology and human factors theory or methods. Further, the model is generic and can be applied to any domain, and countermeasures derived from systems perspective based analyses are aimed at then entire system, and not just individual operators. Most importantly taking a Swiss cheese perspective ensures that, in addition to individual operator failures, system wide failures are considered during error management efforts.

The authors propose that the Swiss cheese model be applied in road transport for error-related study and error management purposes. Adopting the Swiss cheese model as a framework for collecting and analysing human error-related data in road transport is attractive for a number of reasons, including:

- in addition to the errors made by road users, it considers the latent conditions throughout the system that led to the errors being made;
- it recognises the fallible nature of humans and accepts that errors will occur;
- it promotes the development of appropriate countermeasures that are designed to treat both the latent conditions within the system and the errors made by operators;
- it promotes the development of error tolerance within systems;
- it promotes a shift in focus from the role of the individual road user to the system wide failures involved in accident causation, removing the apportioning of blame to individual road users.

HUMAN ERROR AND ROAD TRANSPORT

Compared to other domains in which human error has been identified as a major problem, the construct has previously received only limited attention from the road transport research community. Of the research that has been conducted, the majority has taken a person approach to error, attempting to identify and classify the errors made by different driver groups and also the psychological factors involved in the production of these errors. For example, a large portion of the research conducted to date has involved the use of the Driver Behaviour Questionnaire (Reason, et al, 1990), a subjective questionnaire which is used to identify the different error types that have been made in the past by drivers. The systems perspective approach has received only limited attention to date within road transport, but research using this approach has increased markedly in recent years. For example, Wierwille, Hanowski, Hankey, Kieliszewski, Lee, Medina, Keisler & Dingus (2002) describe a comprehensive study that was conducted at the Virginia Tech Transportation Institute in order to, amongst other things, investigate the nature and causes of driver errors and their role in crash causation. On the basis of an observational study of road user error at over 30 problematic road transport sites, Wierwille et al (2002) developed a crash contributing factors taxonomy of latent conditions and driver errors. According to the taxonomy, there are four different groups of factors that contribute to driver performance problems that occur during crashes: inadequate knowledge, training and skill; impairment; willful behaviour; and infrastructure and environment.

ERROR MANAGEMENT

Error management programs are employed in most safety critical systems in order to identify, remove, reduce or manage the errors that are made by operators. Such programs use a combination of methods to develop a deeper understanding of the nature of, and factors surrounding, error occurrence in a particular system. On the basis of this, targeted countermeasures or error tolerance strategies are developed. A key feature of an effective error management program is the collection of specific information on the different types of human error made in a system, including:

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

Such information is then used, amongst other things, to inform the design and development of error tolerant systems, and the development of countermeasures, remedial measures and strategies designed to eradicate or reduce error in systems. The literature indicated that there are a plethora of error management-related techniques available, including accident investigation, human error identification, human reliability analysis, incident reporting schemes and error management training programs.

THE SYSTEMS PERSPECTIVE AND ROAD USER ERROR

As a result of the lack of human error-related research conducted to date in road transport, there is currently a lack of knowledge and understanding of road user errors and of the latent conditions residing throughout the Australian road transport system that can cause these errors. The review of error management approaches leads us to conclude that the concept of error management has only previously received limited attention in road transport, and therefore that there is currently a lack of the methods with which to collect the error-related data required to enhance our current understanding of road user error and latent conditions within the Australian road transport system.

It is our opinion that adopting a systems perspective model of error in the road transport domain could lead to a greater understanding of latent conditions and road user error, which in turn could inform the development of strategies designed to promote error tolerance within our 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 Swiss cheese model 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 Australian road transport system a breakdown of the different organisational bodies, authorities and operators, (e.g. federal road transport authorities, road users etc) that occupy the different organisational levels within the system is required. This 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 in order to develop appropriate countermeasures and error tolerance 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.

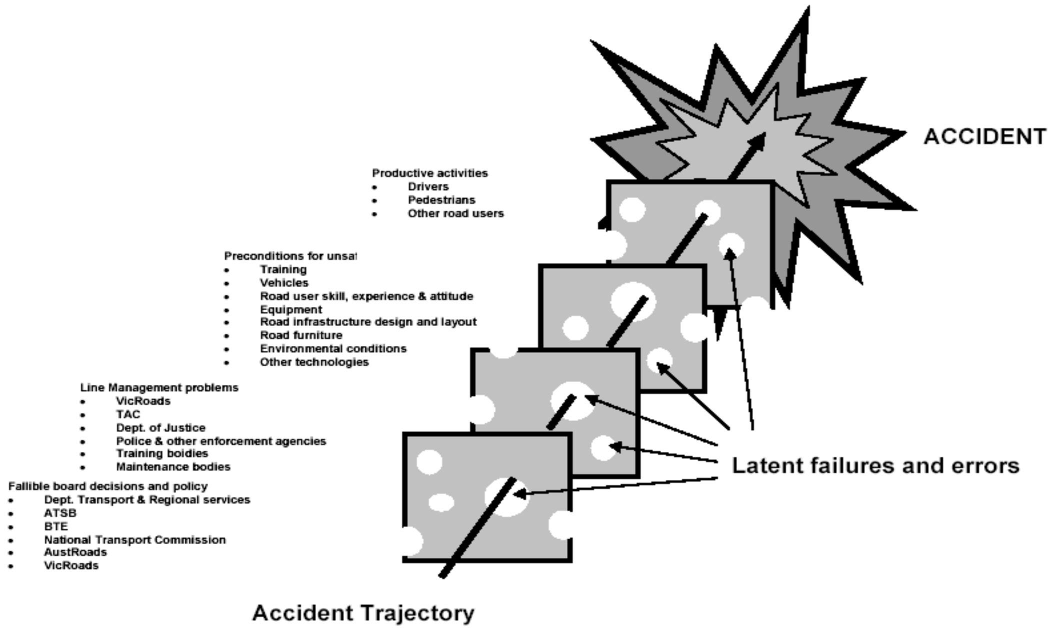

Figure 2. Road transport systems perspective organisational levels.

Taking the systems perspective on road user error in the Australian road transport system, it is proposed that road user error is a function of various latent or error causing conditions residing through our road transport system. Examples of these latent conditions include inadequate roadway design, inappropriately located road signage and traffic devices, inadequate vehicles, and also interpersonal factors such as incapacitation, distraction, inadequate training and experience. These latent conditions, when present, can impact road user behaviour in such a way that leads to an error of some sort being made. On the basis of a review of the literature, a prototype model of road user error and contributing conditions was developed. The model is presented in figure 3 and highlights the interaction between contributing conditions and road user behaviour that leads to errors being made. According to the model the following five categories of contributing conditions impact road user behaviour in a way that leads to road user error of some sort:

1. Road infrastructure. Refer to those inadequate conditions residing within the road transport system infrastructure, including road layout (e.g. confusing layout), road furniture (e.g. misleading signage), road maintenance e.g. (poor road surface condition) and road traffic rules, policy and regulation related conditions (e.g. misleading rules and regulations).
2. Vehicle. Refer to those inadequate conditions residing within the vehicles that are used within the road transport system, including human machine interface (e.g. poor interface design), mechanical (e.g. brake failure), maintenance (e.g. lack of maintenance), and inappropriate technology related conditions (e.g. mobile phone usage).
3. Road User. Refer to the condition of the road user involved, including road user physiological state (e.g. fatigued, incapacitation), mental state (e.g. overloaded, distraction), training (e.g. inadequate training), experience, knowledge, skills and abilities (e.g. inadequate skill), context-related (e.g. get-home-it-is) and non-compliance related conditions (e.g. unqualified driving).
4. Other Road Users. 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. 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 each of the five categories described 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. 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. The errors can either have no impact on the driving task, be recovered by the driver and have no impact, lead to an accident or safety compromising incident, or lead to further errors being made. A prototype road user error classification scheme describing the different errors made by road users is also presented in figure 3 (error modes). It is proposed that the model of road user error and the contributing conditions and road user error classification schemes are refined and validated during the next stage of this research program, which is a pilot study of error and latent conditions at intersections in Victoria.

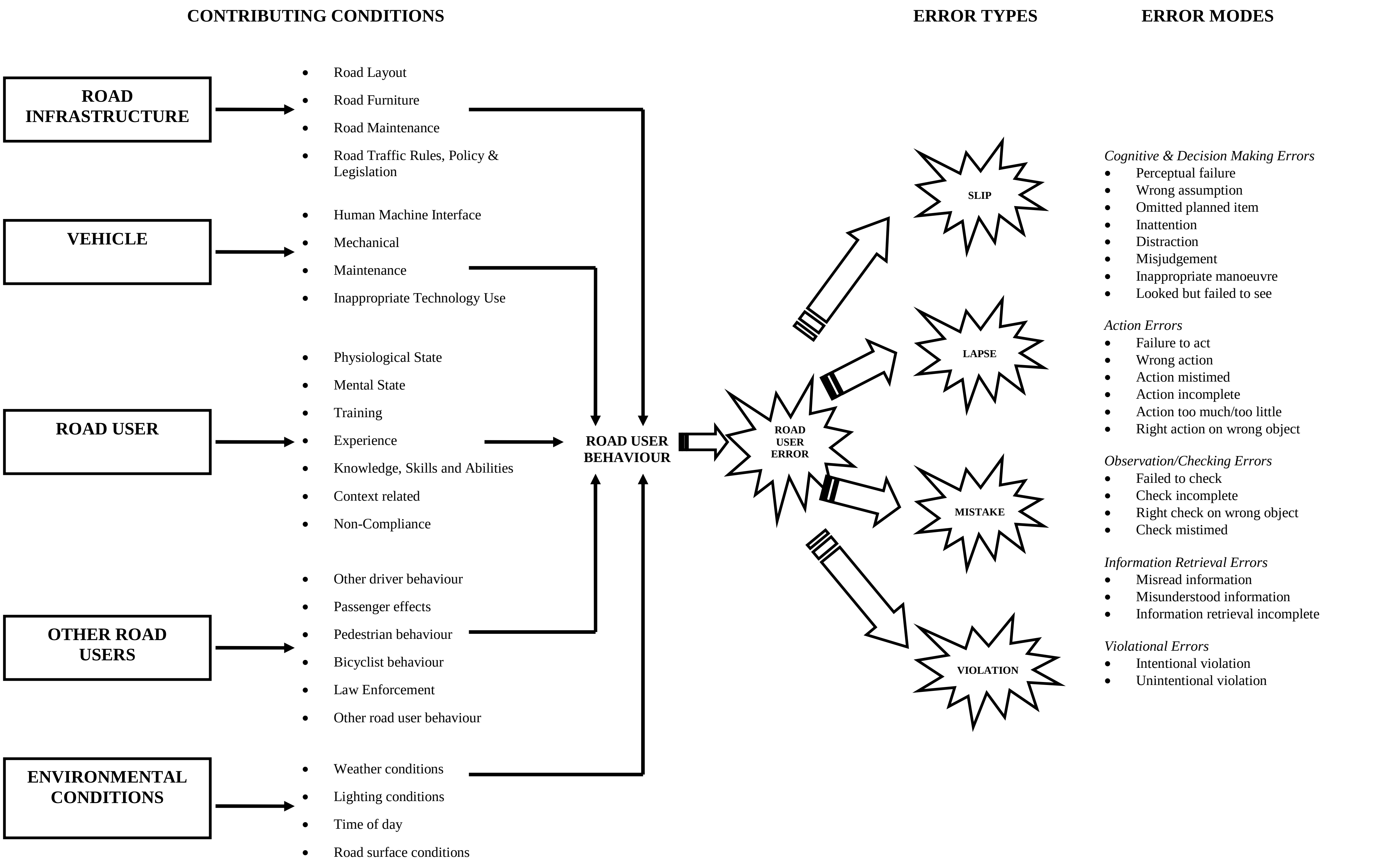

Figure 3. Road User Error Model

TOWARD A FRAMEWORK FOR AN ERROR TOLERANT ROAD TRANSPORT SYSTEM

The literature review conducted during the first phase of this research 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 to enhance system safety through the eradication of errors, systems should be made safer by increasing their tolerance of errors. Despite road safety professionals' best efforts, 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. Rather than focus entirely upon removing road user error through increased training, awareness campaigns and enhanced technology, effective error management in road transport should instead focus on increasing the road transport systems tolerance of 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 tolerance 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 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 proposed framework (presented in figure 4) 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 or error causing 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.

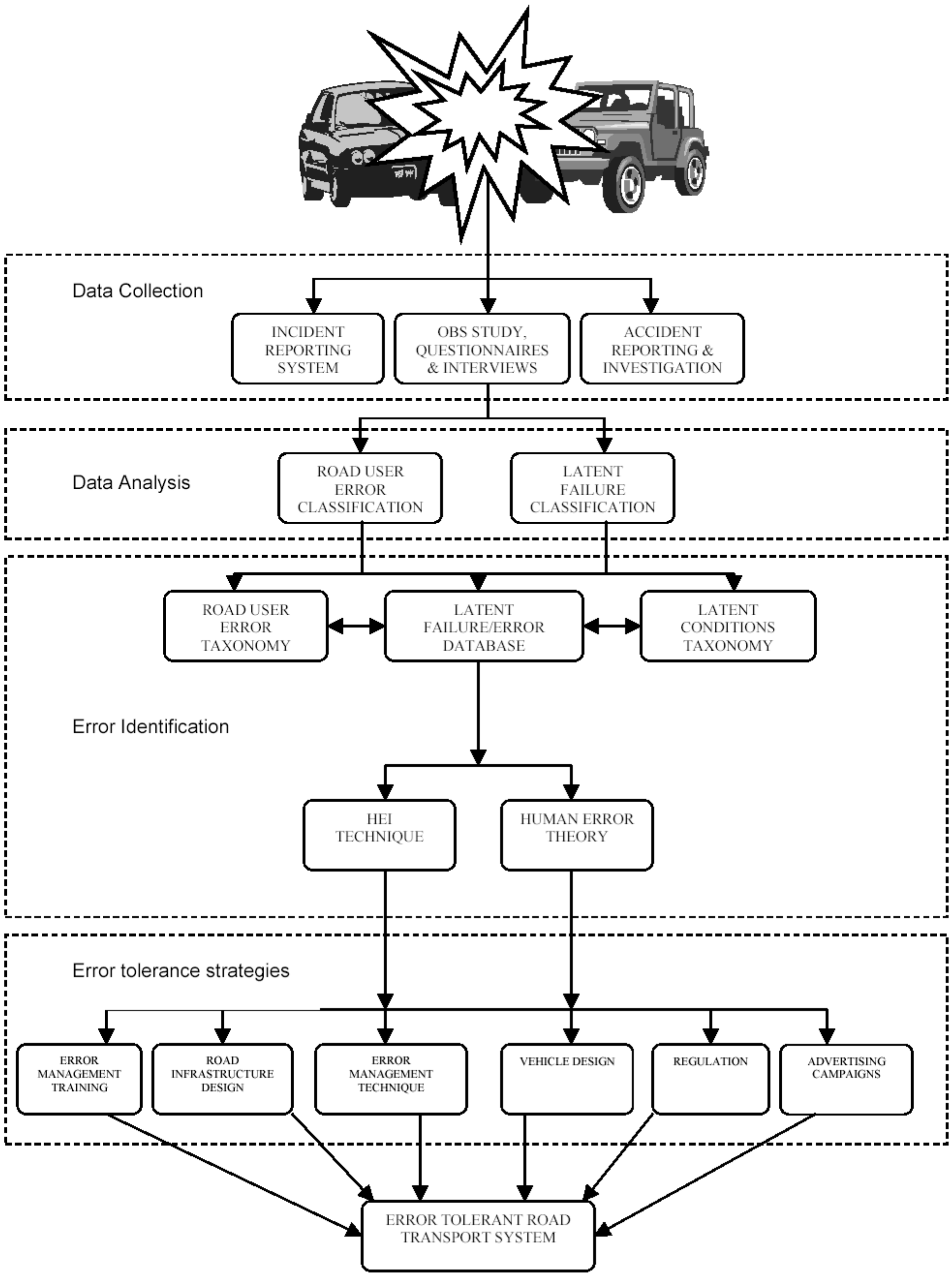

Figure 4. A framework for an error tolerant road transport system.

DISCUSSION

The research conducted indicates, amongst other things, that there is currently a distinct lack of knowledge regarding human error and latent conditions in the Australian road transport system and that there is a lack of 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. In response to this, a model of road user error and a conceptual framework for promoting error tolerance throughout the Australian road transport system as a whole were 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. 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. The next phase of this research program involves the design and conduct of a pilot study on road user error and latent conditions at intersections in Victoria. It is proposed that the methodology required for this study be extracted from the framework.

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