Systems-based Human Factors analysis of road traffic accidents: Barriers and solutions

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Abstract

Safety compromising accidents and incidents occur regularly in the road transport domain. Formal accident analysis is an accepted means of understanding such events and improving safety in most complex safety critical domains. Despite this, there remains no universally accepted, theoretically underpinned framework for collecting and analysing accident-related data in the road transport domain. Further, formal data collection, storage and coding systems to support such analyses do not exist. This paper presents a discussion, based on our experiences from two research programs, on the problems faced when attempting to use systems theory-based Human Factors accident analysis methodologies for identifying, and understanding the relationship between, driver error and system-wide error causing conditions within the road transport domain. The findings from both studies indicate that the application of such methods within road transport is problematic for various reasons, including incompatible data collection procedures, a lack of detail in the ensuing data collected, a lack of theoretically underpinned analysis methods, and a lack of appropriately trained personnel. This paper presents a discussion on the barriers preventing valid, reliable and usable accident analysis within the road transport domain and, in closing, presents a series of proposed solutions to the barriers discussed.

Keywords

Accident analysis, Human Factors, Human error, Road safety

Introduction

Over the past two decades, the 'systems' approach to safety has been applied, with significant safety gains, in most complex safety critical domains (e.g. Rasmussen, 1997; Reason, 1990). Under this philosophy, safety is treated as an emergent property of the overall system, as opposed to solely the responsibility of human operators at the 'sharp end' of system operation. As evidenced by recent road safety strategies, such as the Australian National Road Safety Strategy 2001-2010, (Australian Transport Council, 2000), and the Swedish Vision Zero and the Netherlands' Sustainable Safety approaches, this philosophy is now gaining credence in the road transport domain (Stanton & Salmon, 2009; World Health Organisation, 2004). The Australian National Road Safety Strategy 2011-2021, currently in development, is to be underpinned by a similar philosophy advocating a shared responsibility for safety, an appreciation of the limits of human performance and tolerance, and a forgiving road transport system. The implementation and effectiveness of such an approach is contingent upon various key elements, one of which being the acquisition of appropriate evidence to support systems-based strategy development.

In other safety critical domains, theoretically underpinned, systems-based accident analysis is an accepted approach for identifying and understanding the causal factors involved in safety compromising accidents and incidents, and for informing the development of strategies and countermeasures designed to improve safety (Cassano-Piche et al, 2009). Despite the acknowledgement by the road safety strategies described above that accidents are a systems problem, there is little evidence of the application of systems-based accident analysis methods in a road transport context. The purpose of this article is to discuss, based on our experiences derived from two research programs, the challenges faced when attempting to use systems-based Human Factors theory and accident analysis methodologies in the road transport domain. In closing, a series of solutions to the barriers discussed are presented.

The systems perspective on accident causation

Considerable evidence for a systems approach to safety has been gathered in most safety critical domains. Such an approach is based on the notion that human performance is a function of many interacting system-wide factors. Safety is no longer solely the responsibility of front line operators; rather, the responsibility is shared between actors across all levels of the complex sociotechnical system (e.g. Regulators, policy makers, designers, line managers, manufacturers, supervisors, and front line operators). In the context of human error and accident causation, for example, it is now accepted that errors are a consequence of 'systems' failure, rather than merely aberrant psychological factors within individuals; human error is thus no longer always seen as the primary cause of accidents, rather it is treated as a consequence of latent failures residing within the wider system (e.g. Reason, 1990). In a road safety context, elements of the system beyond road users, such as vehicle design and condition, road design and condition, road policies, and so on, all shape driver behaviour on the road.

Across the safety critical domains, various models of accident causation exist (e.g. Leveson, 2004; O'Hare, 2000; Rasmussen, 1997; Reason, 1990). The most prominent of these are systems-based models (e.g. Reason, 1990), and it is now widely accepted that the accidents which occur in complex sociotechnical systems are caused by a range of interacting human and systemic failures. Undoubtedly the most popular and widely applied model is Reason's (1990) systems perspective model of human error and accident causation. The 'Swiss cheese' model (presented in Figure 1), as it is more commonly known, focuses on the interaction between system wide inadequate (referred to as latent) conditions and errors and their contribution to organisational accidents. Based on a layer by layer description of complex systems (e.g. Board and company management level, line management, front line operators) the model purports that weaknesses in the systems defences, created by inappropriate or inadequate decisions and actions made by actors at all levels of the system, allow accident trajectories to breach defences and cause accidents.

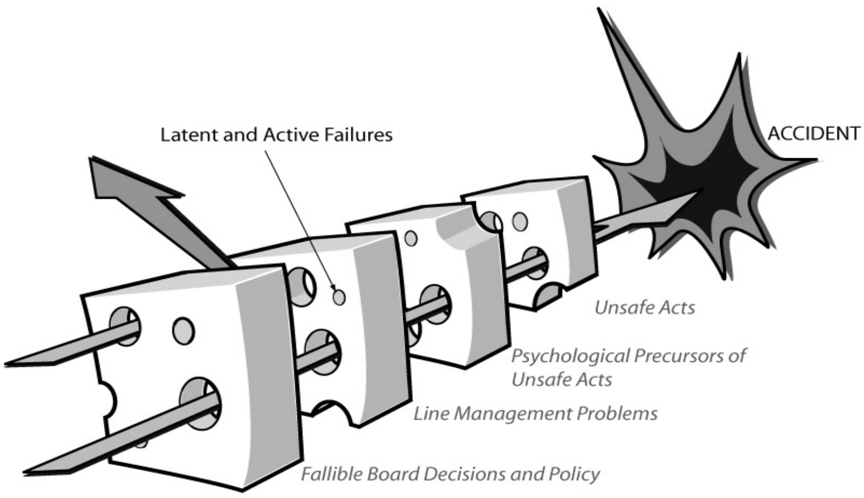

Figure 1: Reproduction of Reason's Swiss cheese accident causation model (adapted from Reason, 2000).

Systems-based accident analysis and investigation

Accident investigation is the most widely used method for clarifying the basic, contributing and immediate causes of accidents and identifying appropriate measures to prevent occurrence of similar events in the future (Roed-Larsen et al, 2004). One popular approach which has been applied across a range of safety critical domains is the Human Factors Analysis and Classification System (HFACS; Wiegmann & Shappell, 2003). Based on Reason's Swiss cheese model, HFACS considers both the errors at the 'sharp end' of system operation and also the latent conditions involved in a particular incident or accident. Although originally developed for the aviation domain, the flexibility and utility of the approach is such that it has since been applied for accident analysis and investigation purposes across a wide range of safety critical domains, including civil and general aviation (e.g. Lenné et al, 2008), coal mining (Lenné et al, 2009), rail transport (Baysari et al, 2008), and healthcare (El Bardissi et al., 2007) to name only a few.

HFACS builds on Reason's model by specifying different failure categories and associated failure modes at each of the different organisational levels specified. HFACS therefore comprises a series of error and latent failure modes spread across the following four organisational levels: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organisational influences. The structure of the HFACS method is presented in Figure 2, which also includes a representation of how the HFACS methodology maps onto Reason's systems perspective model of human error. Working backward from the immediate causal factors, analysts classify the errors and associated causal factors involved using the taxonomies presented at each level.

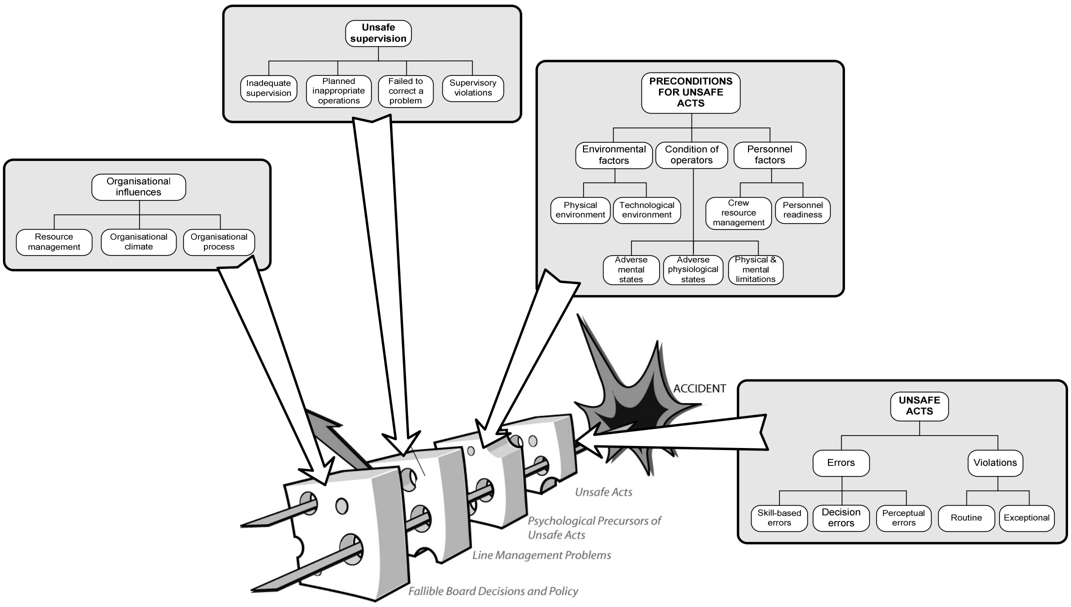

Figure 2: HFACS mapped onto Reason's Swiss Cheese model.

Systems-based accident analysis in the road transport domain?

Systems-based accident analysis and investigation has been applied, with significant success, in a range of safety critical domains. Systems-based models, such as Reason's (1990), and the ensuing accident analysis methodologies, such as HFACS, are equally as applicable in road transport as they are in aviation, process control, rail transport and the range of other domains in which they have been applied successfully. Despite this, the literature indicates that such applications have to date been sparse.

The Human Factors Group at MUARC have recently undertaken two research programs involving the exploratory application of systems theory-based accident analysis and investigation methods in the road transport domain. In the first study (Salmon et al, 2009), an attempt was made to analyse data from the National Coroners Information System and the VicRoads database of police-reported crashes using the HFACS approach (an attempt was also made to analyse data from the National Coroners Information System for New South Wales; however the data was deemed incomplete). In the second study (Brace et al, 2008), crash data from two accident black spot intersection sites in Melbourne were analysed. The findings from both studies indicate that the practical application of systems-based accident analysis methods within road transport is problematic for various reasons. Ostensibly, these difficulties surround three facets of accident analysis and investigation: 1) the domains acceptance of the theory underpinning the methods used; 2) the quality of the data obtained, its collection and storage, and the analysts required for applying accident analysis methods; and, 3) the accident analysis methodologies available. A discussion on the issues identified in each area is presented below.

Theoretical underpinning: why doesn't the road transport system like the taste of Swiss Cheese?

Most accident analysis methodologies are underpinned by systems thinking of the like displayed in Reason's Swiss cheese model. The model is highly applicable in a road transport context, with each of the levels specified applicable to road transport systems, and yet it does not appear to have been widely accepted or applied in such a fashion. It is notable that recent road safety strategies, such as the Swedish Vision Zero strategy, the Netherlands' Sustainable Safety approach, and the Australian National Road Safety Strategy 2001-2010, take on much of the systems approach philosophy, including the fallibility of human operators, and the notion that safety is a responsibility shared between the actors across all levels of the complex sociotechnical system and is not just the responsibility of front line operators (i.e. road users) alone. Despite this, translation of the models principles into practical approaches in road transport has not yet been achieved.

Notwithstanding the model's ubiquitous appeal, it does have a number of gaps that may explain its lack of practical application in a road transport context. Firstly, there are no structured, road transport specific, methodologies associated with the model; valid data collection and analysis methods for road transport, underpinned by systems theory, do not yet exist. This is not the case in other domains in which the model has enjoyed significant success; for example, in the aviation domain the HFACS accident analysis method was developed based on Reason's model. Secondly, since the model is generic in terms of domain of application, it lacks a clear definition of the different latent failures residing at each of the levels within the model and also lacks a taxonomy of 'unsafe acts'; analysts are therefore given little guidance in the identification of the errors and latent failures involved in accident and incidents. Thirdly, the model is descriptive rather than analytical, and fourthly, Wiegmann & Shappell (2003) point out that because the model was originally aimed at academics rather than practitioners, the explanation of the unsafe acts level was highly theoretical and analysts and investigators have had difficulties applying the model in the 'real-world'. Finally, road safety practitioners may simply not be aware of the recent theoretical advances made in terms of accident causation. Significantly, the gaps discussed can all be removed through further research and methodological development specific to road transport.

Data and analysts: what is collected, when, by whom, with what, and where is it held?

In any complex sociotechnical system, our understanding of accidents is constrained by the quality of the data gathered and the experience and training of the analysts who analyse it (Grabowski et al, 2009). Road transport is no different, and there are various issues surrounding the data available, and its collection, storage and analysis. Also, the resources required for collecting, storing and analysing such data would be considerable, and questions remain over who would be responsible for collecting, analysing, and storing the data required for systems-based accident analysis.

In the studies undertaken, various issues were found with the accident data analysed. The quality of the data collected and thus available for road traffic accident analysis is a significant concern. Currently, the data collected for accidents in the road transport system focuses on a limited set of parameters, mostly surrounding the road user (e.g. intoxication) and their behaviour (e.g. speeding or driving without due care and attention). Other data may also be collected, such as the environmental and road conditions and condition of the vehicles involved, however other key systemic factors are also often ignored, including the road infrastructure, level of training received, inappropriate legislation, and conditions promoting violations (e.g. Wagenaar & Reason, 1990). In the cases studied, often an immediately apparent cause (e.g. speeding, driving under the influence of alcohol or drugs) was recorded, and any other pertinent data was subsequently left unrecorded. Often, it appeared that the primary data collector (namely the police who arrive at the scene) may unintentionally disregard latent contributory factors to the crash. For example, if a driver is found to have a blood alcohol level over the legal limit, an intersection with a confusing layout may not be considered.

The procedure and methodology used to collect accident data is also a key factor in the quality of the ensuing information derived. Despite the fact that many road traffic accident error and contributing factor taxonomies have been developed over the years (e.g. Stanton & Salmon, 2009; Sabey & Staughton, 1975; Treat et al, 1979; Wierwille et al, 2002), a universally accepted, systems-based classification scheme does not yet exist. Further, the extent to which these approaches are underpinned by accident causation theory is questionable. Data collection (e.g. accident-reporting systems) systems are currently not based on existing theoretical frameworks that take human-error or other human-factors issues into consideration. This prevents a more in-depth understanding of the causal factors underlying accidents, and their complex interactions. A theoretically underpinned, systems-based, data collection methodology is therefore required.

The personnel involved in collecting accident data within the road transport domain is also an issue. Often they may not have received appropriate training in Human Factors and the systems approach to accident causation, and so their understanding of the role of systemic failures in accidents may be limited. One way around this is to use teams of trained investigators who follow the Police Force to accident sites (this is an approach that has been adopted in Europe). A feasibility study investigating the potential use of accident analysis teams is therefore recommended.

Where the data collected should be stored, in what format, and by who is also of concern. The culmination of accident and error-related data collection in most safety critical systems is typically a database of some sort, containing descriptions of the different accidents that have occurred within a particular system, along with their associated causal factors and consequences. This can be an extremely powerful resource and can be used for a number of purposes including in-depth studies, the identification of different accident and error trends, the development of domain-specific taxonomies of error, quantitative error analysis, and to inform the development of accident and error countermeasures. Whilst a myriad of crash incidence databases do exist within the road transport domain, typically the data contained within them does not stretch to classifying the different driver errors and the causal factors involved in any detail. Appropriate systems-based databases do not yet exist within road transport. Crash databases containing data regarding the road user errors and system-wide contributing factors are therefore required.

The resources required to collect the data that is required to support systems-based accident analysis is also problematic. Comprehensive data collection in this sense requires significant resources in terms of time invested at the accident scene and also in terms of the actual coding and analysis of the data. It is questionable whether such time could be made available in the current system, and the responsibility for undertaking data collection and analysis activities remains unclear. The feasibility of employing exhaustive, systems-based accident data collection systems requires further examination in a road transport context.

The problem of data currently not being exploited is also apparent. Near-miss incidents, those events or unsafe acts that occur where the sequence of events could have caused an accident if it had not been interrupted (Jones et al, 1999), represent a potentially powerful, yet currently ignored, data set available within the road transport domain. Near miss incident reporting systems, used to collect data regarding near miss incidents, errors, safety compromising incidents, and safety concerns, are common in most safety critical domains, including the aviation (e.g. Aviation Safety Reporting System), healthcare (e.g. MedWatch) and nuclear power domains (e.g. MARS). They work on the premise that near miss incidents are indicators of accidents waiting to happen, and so preventative measures can be taken before large-scale or costly accidents occur. The importance of collecting and analysing near miss data has been articulated by many (e.g. Reason, 1997; Jones et al, 1999) and it is a well established method of improving safety in complex sociotechnical systems (Koorneef, 2000; cited in Ternov et al, 2004). The utility of reporting near miss incidents lies in the ability to generate large amounts of data that would otherwise go unreported; so long as they are analysed correctly, and the appropriate conclusions are drawn and acted upon, near misses can mobilise system's defences against more serious future occurrences (Reason, 1997). They also provide a powerful reminder of the hazards present within a particular system. Currently, however, such systems do not exist within road transport, and it may be that new technologies, such as Intelligent Transport Systems and GPS-based route navigation systems may provide us with new avenues of collecting near miss data. Again, further investigation is required regarding the potential role of advanced technologies such as ITS and the collection of near miss incident data.

Systems-based road traffic accident analysis methods

Unlike other safety critical domains in which accidents and incidents are a significant problem, the development, application, and validation of systems-based accident analysis methods in road transport has largely been ignored. Such approaches are beginning to emerge in Europe, for example, Sandin & Ljung (2007) describe the Driver Reliability Error Analysis Methodology (DREAM) accident analysis methodology, developed specifically for the analysis of road traffic accidents. To date, however, such methods have not been developed for the Australian road transport system. Without such approaches, the utility of accident analysis in the road transport domain is limited significantly. For example, existing approaches, which focus primarily on the road users involved, can be criticised for their contribution to the individualistic blame culture currently extant within road transport and the fact that the resultant countermeasures (e.g. poster campaigns, disciplinary measures, and retraining), are focussed upon reducing the variability in human behaviour at the sharp end of system operation rather than the inadequate conditions present in the system itself (Reason, 2000).

Conclusions

In most safety critical domains, safety has been improved through the application of human error models and methods (Sheridan, 2008). Structured, theoretically underpinned accident analysis and investigation is one such proven method of enhancing safety in these domains (Cassano-Piche et al, 2009). It is apparent, however, that, despite being highly applicable, our knowledge of accidents and accident causation, and the methods that we use to understand it, has, to a large extent, been ignored by the road safety community. Whilst the systems theoretic perspective on accident causation is now gradually becoming accepted within the road transport domain (e.g. Stanton & Salmon, 2009; World Health Organisation, 2004), it is notable that the approach to accident analysis and investigation remains, on the whole, individual road user oriented and dated from a theoretical perspective. Our experiences on two research programs investigating the utility of systems-based accident analysis within road transport indicate that there are various reasons for this, surrounding the quality of the data available, its collection, coding and storage, the training and experience of the personnel available to analyse road traffic accidents, and the lack of appropriate methodologies available to analyse them. A summary of the most prominent barriers, and, potential solutions, is presented in Table 1.

The conclusion that existing road traffic accident data does not support systems-based accident analysis is perhaps the most important finding to emerge from our research. There is sufficient evidence across the safety critical domains that support the utility of systems-based accident analysis, and it is now an accepted approach for understanding accidents and for informing the development of strategies and countermeasures designed to improve safety (Cassano-Piche et al, 2009). Despite the need for systems-based analysis of road traffic accidents, our research has highlighted that such analyses are currently not possible, and that much further work is required before such analyses become viable. The issues surrounding the data available for road traffic accidents are represented in Figure 3. In both figures, the data available the first of our studies (Salmon et al, 2008) is mapped onto the accident causation model underpinning this research (e.g. Reason's Swiss cheese model). This clearly shows that the data available covers mainly the road user (e.g. driver, motorcyclist) involved and a limited sub set of environmental (e.g. speed zone, weather conditions), equipment (vehicle type), and contextual-related factors (e.g. day, week, season). Clearly, a complete systems analysis is not supported by current crash data, with higher level factors currently not reported, such as poor roadway/infrastructure design, poor operating procedures, and conditions promoting violations (Wagenaar & Reason, 1990).

Table 1. Barriers to systems-based accident analysis in road transport, along with proposed solutions.

Barriers preventing valid and reliable applications in road transport	Proposed solutions
1. Insufficient data collected to support analyses; 2. Data collection is often focussed on a single cause (e.g. speeding, alcohol); 3. Resources required to collect appropriate data; 4. Expertise required to analyse data; 5. Lack of a database to store data; 6. Lack of a standardised, theoretically underpinned methodology for analysing road transport accidents and incidents.	1. Feasibility study to examine the potential for collecting 'systems' data to support systems-based road traffic crash accident analysis; 2. Development of theoretically underpinned, systems-based data collection methodologies (e.g. road user error and crash contributing factor classification schemes); 3. Provision of training in systems-based human error and accident causation theory for accident data collectors; 4. Feasibility study investigating the development and use of accident analysis teams; 5. Development of road user error and crash contributing factors database, linked to data collection and analysis methodologies 6. Development and validation of theoretically underpinned, systems theory based road traffic accident analysis methodology

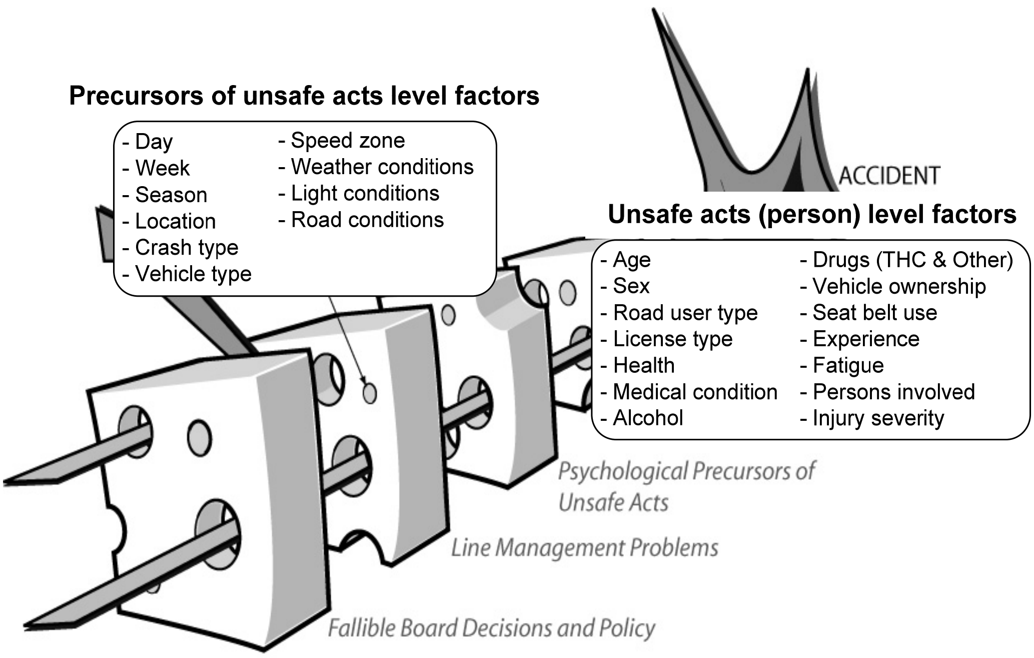

Figure 3. Fatal road traffic accident data mapped onto Reason's Swiss Cheese accident causation model.

It is concluded that much further research is required to examine the feasibility of applying theoretically underpinned, systems-based accident analysis systems within the Australian road transport system. Although our initial work in the area indicates that much further work is required to enable such an approach, it is our view that the work required is achievable provided theoretically driven research is undertaken. Once the feasibility of such an approach is assured, the following lines of enquiry should be pursued in order to make steps toward the successful design and implementation of systems theoretic-based accident analysis methodologies within road transport. New standardised systems-based approaches are required for accident and incident data collection, storage, and analysis. Data collection systems underpinned by systems theory, and associated databases that are structured to produce data focussing on the overall system, as opposed to just individual road users, are required. Training for analysts in accident causation theory and the systems perspective on human error is should also be provided, and regular workshops demonstrating systems-based accident analyses should be used. Systems-based accident analysis methods, the type of which are well developed and applied in other safety critical domains (e.g. Rasmussen, 1997; Wiegmann & Shappell, 2003) are also required for analysing, and learning from, road traffic accidents and incidents. In particular, the shared responsibility for safety element requires that such approaches focus on the higher government, local government and line management failures, as well as individual road users and equipment failures. The development and application of systems-based data collection, storage, and analysis methods in support of the National road safety strategy is likely to provide appropriate evidence to support the design of appropriate systems-based strategies.

In closing, it is clear that systems-based accident causation models, and the associated accident analysis methods, have a significant role to play in the enhancement of safety within the road transport domain. It is our opinion that the application of structured, theoretically underpinned approaches, although to date ignored to a large extent, would be fruitful for road safety efforts. Reason's Swiss cheese perspective model clearly applies, and yet the application of systems-based accident analysis methods has been limited. Although strong barriers to the application of such methods exist, future applications are urged. The importance of such applications in the successful implementation of safe systems framework-based strategies and policies is paramount. Although the nature of road transport is such that we have been left behind somewhat in terms of the development and practical application of such approaches, it is clear that we know where we need to go, and how we can get there. Ongoing, theoretically underpinned research and methodological applications are therefore urged in order to facilitate this journey.

Acknowledgement

The research underpinning this article was undertaken on two projects, the first (Salmon et al, 2009) of which was funded by the NRMA Road Safety Trust, and the second of which (Brace et al, 2008) was funded by the Australian Transport Safety Bureau (ATSB) and the Monash University Accident Research Centre Baseline Research Program.

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