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Systems Thinking in Road Safety Management

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Abstract

Effective implementation of the “Safe System” approach requires ‘systems’ thinking in an integrated and holistic strategy involving all road safety disciplines. This paper examines safety systems management to gain a clearer perspective on managing road safety as a whole, rather than individual parts in isolation. The identification of a comprehensive system of good practice in data collection and risk analysis, root cause analysis incorporating contributory factors, together with critical performance monitoring leads to a more proactive approach to reform capable of achieving road safety targets. The paper identifies ‘System Safety’, explores the historical development of systems thinking and investigates transport and industry safety management to gain insight into how best to use the experiences in general road safety management. Road safety advancement is calling for a more systemic and dynamic analysis of road trauma risk factors. The original Haddon’s Matrix, used in crash investigations since the 1970’s is now questioned for sufficiency to support Safe Systems analysis. Psychologists such as James Reason and others have developed injury factor analysis tools that have been applied in occupational and aviation safety. These approaches support the analysis of latent root causes – methods that have generally not been applied in road safety. Apart from work-related road safety, this approach of systemic analysis has largely been absent. A critical assessment calls for a deeper analysis of road trauma data and more comprehensive use of key performance indicators in a similar application to that used in the medical and allied health services.

Key Findings

- There is an urgent need to maximise root cause analysis and contributory factors to identify and eliminate systemic risks in crash investigations.
- A safe system requires ‘systems’ thinking to holistically address the critical risks of the road environment, the vehicle and the road user.
- Lessons can be learned from medical and allied health services, the aviation and transport industries and the work health and safety sector.

Glossary

ABS Anti-lock braking system
ADRs Australian Design Rules
EDRs Event Data Recorders
ESC Electronic Stability Control
GLS Graduated Licensing System
iRAP International Road Assessment Program
IRPAP International Road Policing Assessment Program

KPIs Key Performance Indicators
NCAP New Car Assessment Program
WHS Work Health and Safety

Introduction

Notwithstanding the development of the Safe System approach, there is no comprehensive safety management approach for measuring performance and outcomes for road

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safety. A holistic, integrated and systems approach requires root-cause analysis of crashes, contributory factors assessment, a prevention-based focus and risk mitigation strategies.

This calls for system risk assessments as part of a proactive approach to road safety. With the advent of the “Safe System” there has been a call for a paradigm shift in the way we conceptualise injury risk from crashes on our roads (Grzebieta & Rechner, 2001; Rechner & Grzebieta, 1999; Williamson, 2021). Here, the integrated crashworthy system recognises the vehicle, road users and the road environment in a holistic approach.

Programs, such as the International Road Assessment Program (iRAP) and the New Car Assessment Program (NCAP), are taking more proactive approaches to road injury prevention, by identifying ways to make the road and traffic system as well as motor vehicles inherently safer for human use. The International Road Policing Assessment Program (IRPAP) (Shuey, 2013) provides similar star-rating benchmarks for road policing, enforcement and road safety.

To mitigate the behavioural risks of road users, systems must ensure greater support to guard against low-risk road user actions with training, legislation, and enforcement, combined with road traffic systems that passively encourage safe behaviours, such as self-explaining roads (Theeuwes & Godthelp, 1995) and traffic calming devices. The solution lies in the integration of the traditional ‘silo’ approach within the disciplines accompanied by accountability of the collective system managers. There has been scant regard to road traffic *system safety*.

Haddon’s Matrix

The ‘scientific method’ of analysing road injury causation was embraced in the 1960s following the work of Dr William Haddon, a public health expert. The original matrix called for the identification of contributing factors prior to, during and after the crash event, grouping them into three categories, being the vehicle, the road environment and human factors (Haddon, 1968). That is, in a manner similar to traditional medical epidemiological examination of how infectious diseases occur, i.e. injury epidemiology analysis of the components of a host (human), a vector or agent (vehicle) and an environment (road) to find how the transfer (in this case of harmful energy forces) would result in injury.

[Table 1](#) presents the 2-dimensional risk factor assessment matrix as developed by Haddon and populated in the context of a police crash investigation. This is used to assess the interrelationship between the road environment at the pre-crash (prevention), crash state (stop the bleeding) and the post-crash stage (don’t let it happen again). While acknowledging this is not the panacea in capturing all dimensions as developed by Haddon including the social environment and other potential elements, it seeks a more thorough analysis than traditional police crash investigations.

This injury analysis model can be applied simply for individual crashes and at the strategic level for road safety. This analysis provides information about the relative contributions of road injury factors, thus enabling a focus on

investments in prevention programs to address those risk factors that occur most often in fatal and serious injury crashes.

This was the springboard for a more systematic analysis of road trauma. Injury specialists, particularly in the Western world, began to adopt this method with bio-mechanical engineers considering the most prevalent motor vehicle features that contributed to more severe injuries, civil engineers examining the most prevalent road environment features, and behavioural scientists investigating the most prevalent unsafe road behaviours contributing to crashes and injuries. Haddon’s approach thus enabled road safety practitioners to identify clusters of road injury factors within the matrix that could then be investigated further with social, behavioural and engineering research methods. Such analysis of data on the contributing factors to, and circumstances of, crashes formed the basis of the prevailing strategic approach to road safety management.

Another important concept in injury prevention highlighted by Haddon’s work was passive versus active safety (Haddon, 1980). Active safety occurs when the human host does something to prevent or ameliorate harm. Passive safety occurs when conditions are designed to prevent human errors becoming harmful or injurious. In other words, passive safety does not rely on humans to make decisions in favour of safety and compensates or corrects their mistakes.

However, observing the data clusters within the cells of Haddon’s Matrix can be misleading if the interrelationships between and among the various factors are not understood. Moreover, the Matrix does not serve as a tool for explaining what caused the injury factors to manifest, nor does it enable the injury analyst to know what factors are most important to address. In other words, it provides only snapshots of the components that contributed to injury. While Haddon addresses three phases of injury causation and a multiplicity of contributing factors, his model does not recognise the dynamic and compounding nature of injury causation processes; nor does it convey the interrelationships among the cells of the matrix. Instead, injury factors appear in the Matrix as discrete occurrences. Individual road crashes, particularly fatalities, may be reported with detailed chronologies of events but the data are then dissected and filed in categories where groupings of contributing factors are aggregated in human, road and vehicle sections. Moreover, the chronology of events is usually limited to what the road crash investigator can find at the scene of the crash. In non-fatal crashes and even in some fatal crashes, it is rare, for example, that police collect data regarding purpose of journey.

The use of the Haddon injury analysis tool tends to treat all contributing factors equally and typically finds that in over 90 percent of crashes, human factors are involved (Hendricks et al., 1999). These factors can be addressed through passive system measures as well as with active behavioural management measures.

In this and other dimensions, the Haddon model does not enable ready analysis of the combined effects of road safety countermeasures being implemented simultaneously

Table 1. Haddon's matrix example, populated for identifying road injury factors

	Road user	Vehicle	Road environment
Pre-crash (Prevention)	Licence (GLS), Status Driver risk profile Impairment Enforcement – strategic, targeted, visibility, effectiveness Education – general and specific deterrence	Roadworthy ADRs, ANCAP ABS, ESC, Airbags, Collision avoidance Lane maintenance Semi-auto vehicle Telematics	Road design, maintenance Divided/barriers Black spot/length Speed limits Road Safety Audits
Crash (Stop the bleeding)	Restraint use (seatbelt, child restraint) Protective equipment use (helmet)	Vehicle crash protective design Road user protection Injury prevention – seatbelts/airbags Lighting Helmets Event Data Recorders (EDRs)	Divided road, road surface, wire rope barriers, run off ditches, cliffs, trees Roadside furniture
Post-crash (Don't let it happen again)	Emergency response Air/road rescue Congestion Trauma management Rehabilitation	Design improvements for emergency access ITS emergency reporting	Emergency breakdown lanes Removable centre barriers on divided roads

(which is often the case in jurisdictions with strategic road safety programs). Elvik (2009) concludes that “there is a need for more research in this area in order to develop more sophisticated models for estimating the combined effects of road safety measures (p.880).”

Moreover, Haddon's model is primarily focused on control factors to identify potential prevention, research and for developing interventions as a brainstorming exercise (Runyan, 2003). Under this approach, risk factors and countermeasures are systematically identified, but often a cost-benefit analysis is used to guide decisions about which countermeasures would be implemented and how far they would go to restrict individual mobility or transport efficiencies (Grzebieta, 2013). For example, road design engineers still accept that 15-20 percent of people will not recover from an injury crash that results from insufficient clear zones on roadsides (Austroads, 2010).

What is needed is further improvements to measuring road safety management performance and a way of better understanding the trends in various crash types, as well as an ability to identify safety risks in the ‘live and dynamic’ road traffic systems. The OECD (2008) has recommended that data including, demographic data, traffic volumes, safety performance indicators (seat belt wearing rates, speeding, etc), and infrastructure factors, and risk management measurement will be necessary to achieve Safe System objectives.

Developments in Injury Analysis

Important developments in crash causes involve foundational root cause analysis (McIlroy et al., 2021; Salmon et al., 2020), to critically identify prevention focused initiatives addressing the higher-order factors and continually asking ‘why’ in the investigative approach. Typically, these root cause analyses are conducted by dangerous goods companies such as Shell and BP when any truck carrying

their fuel has a crash. It is argued that systemic analyses of crashes involving human user behaviours are more effectively achieved through broader organisational changes (Molan & Molan, 2021).

The approach considers contributory factors as a reductionist strategy to discover the various road, vehicle and human factors likely present before, during and after a crash (Haddon). The injury event chain analysis was pioneered by Heinrich (1931) and further developed by Reason (1990) and others. Some *sequential* models, such as the Tripod Beta method (Figure 1), are based on the idea that all ‘accidents’ are caused by organisational failings. However, it is difficult to transpose this conceptual approach to the dynamics of road user interactions.

Reason's contribution was to revise thinking about causation from only examining immediate events to include examination of ‘things’ occurring earlier in time, stressing these pre-existing factors may lay dormant for a long time – even years. His contribution broadened thinking to encompass the possibility that errors can occur due to the system itself.

Models examined by Sklet focused on safety barrier failures within the organisation concluding that “major accidents almost never result from one single cause” (Sklet, 2005, p. 154). Reason, a psychologist, promoted a “Swiss Cheese” model depicting a system of holes in the safety defence system that would enable a hazard trajectory to run its course resulting in a harmful event (Figure 2). He provided evidence that human error is not a cause, but rather a consequence of organisational shortcomings (Reason, 1990). This is not to say that human errors did not occur; rather it was a recognition that human errors are shaped by upstream workplace and organisational factors.

System thinking is not new in the occupational safety field and the aviation industry (Maurino et al., 1995). It just has not been fully applied in road safety. It was 27 years ago

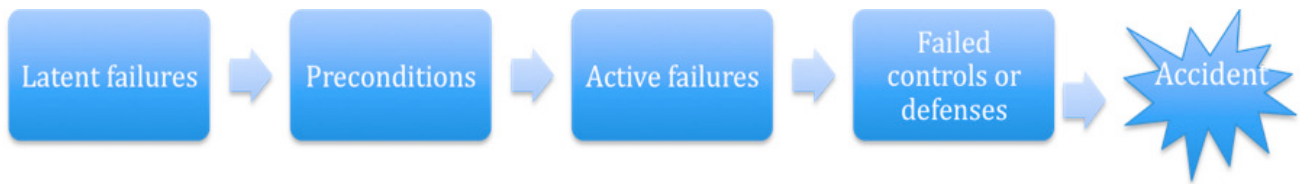


Figure 1. TRIPOD Beta accident causation model (Reason et al., 1989)

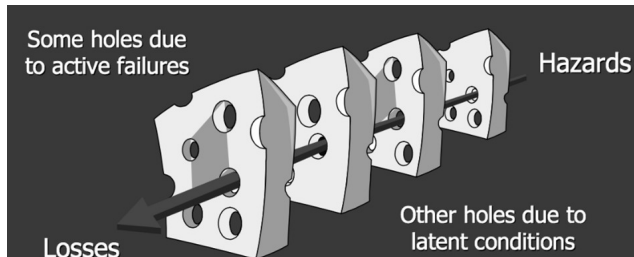


Figure 2. Swiss cheese model of crash trajectories (Reason, 1997)

that Rasmussen (1997) reviewed a range of models for understanding crash causation and emphasised the need for a multi-disciplinary understanding that human activity occurs within a dynamic socio-technical system of interactions.

In addressing root cause factors in injury incidents, it is useful to ask ‘why’ each time a contributing factor is discovered until the system deficiencies are found. Firstly, to state the problem, then ask why the problem occurred. The idea is to keep asking why until an answer cannot be found, thus identifying the root cause.

Working in aeronautics and astronautics, a group proposed a new crash model that calls for “continuous controls of processes, instead of controls on individual system component failures” (Leveson, 2004, p. 250). Unlike the Haddon model, this systems-based model has a stronger focus on understanding why the control system failed and why they made components unstable, than on immediate error factors. It seeks to identify the conditions where an operator error could result in harm.

Newnam and Goode (2015) applied a systems-based approach using the Accimap technique (Rasmussen, 1997) to improve understanding of the systemic factors involved in heavy vehicle crashes, following a study of 29 truck investigation reports by the National Transport Safety Bureau (NTSB) in the United States. The findings suggested that the NTSB reports rarely considered the role of government departments and regulatory bodies in crashes unless their actions impacted on the conditions at the immediate scene of the incident. This omission highlights the need for deeper analysis to identify root cases and contributory factors.

What is system safety?

The road and traffic system is more than infrastructure, vehicles, and road users operating in a live and dynamic envi-

ronment. Effective control of safety risk must therefore involve an understanding of these interactions and intervene in ways that consider the ever-changing process of injury risk.

The recognition of system complexity and dynamic nature of work processes in many industries has led to development of models that do not assume linear or sequential chains of risk factors. Rasmussen (1997) argued that a system-oriented approach based on functional abstraction was needed rather than decomposition of risk factors. Action sequences and occasional deviation in the form of human errors should be replaced by a model of behaviour-shaping mechanisms, including work system constraints, boundaries of acceptable performance, and subjective criteria guiding adaptation to change. Moreover, Rasmussen points out that the concept of an “event” is elusive in the sense that the more specific its definition, the less likely it is to recur. Hence, this form of causal analysis is less valuable as a tool for prevention. It is best to define classes of events that can then be moderated through other conditions being present. The analysis then relies on the ability to decompose processes and factors within a dynamic flow of activity.

A range of other theoretical models has been used in injury prevention fields. A review of these models, specifically for the purpose of finding models to improve road safety, found that the 121 models that might be applied to road safety can be grouped into seven categories – component, sequence, intervention, mathematical, process, safety management, and system models (Hughes et al., 2015). Each type of model applicable to injury prevention may be particularly suited for differing purposes and contexts. It may not be useful, therefore, to find or develop the best model for injury prevention across the board, but it is worth examining the way that road and transport safety research and interventions have been shaped by theoretical models, to see if there are other theoretical constructs that can guide an improved examination of road safety problems and solutions. Hughes et al. (2015), concluded that none of the systems’ approach models have been generally applied in road safety even though they show promise for improving safety in this context.

There is increasing support for the idea borrowed from work, health and safety (WHS) that a systems approach to analysing road injury factors may help to explain the dynamic interaction of the risk factors within a work or driving process and the fact that the conditions built within the system can create risks that sometimes long pre-date the proximal unsafe act that finally resulted in an injury crash, (e.g., inadequate brake maintenance, driver payment

systems, etc.) (Mooren et al., 2009; Williamson & Friswell, 2013).

Applying Systemic Crash Analysis in the Heavy Vehicle Transport Sector

The Australian road freight industry has a high rate of worker fatalities, at 18.6 per 100,000 workers compared with the overall Australian work-related fatality rate of 1.9 deaths per 100,000 workers (Safe Work Australia, 2013). In the US, an examination of work-related deaths and injuries found that truck driving amounted to 12 percent of all worker deaths accounting for more fatalities than any other occupation. Truck drivers also accounted for more non-fatal injuries than all other occupations (Knestaut, 1997). Similarly, Canadian government statistics for work-related fatalities of workers in Federal jurisdiction employment found that in 2011 around 60 percent of these fatalities occurred in the road transport sector (Employment and Social Development Canada, 2014). Furthermore, it was reported that 6,556 road transport workers sustained disabling injuries on the job that year.

It is well established that driver fatigue is one of the most prevalent factors in truck crashes (Crum & Morrow, 2002; Dingus et al., 2006; Feyer et al., 2002; Feyer & Williamson, 1995; Hanowski et al., 2009). Data from a study in Australia of 848 insurance reports of major truck crash investigations (defined as crashes with losses costing \$A50,000 or more) found that fatigue was involved in a third (34%) of the crashes, and was the greatest contributing factor (NTARC, 2020). It was noted that driving on long stretches of straight roads, speeding, and fatigued driving are quite common experiences, particularly for long distance truck driving. Given the nature of truck driving, these risk and crash factors are more likely to be prevalent in this group of road users. In an Australian survey (Williamson & Friswell, 2013), more than one quarter of truck drivers reported that they experience fatigue while driving for work in half or more of all trips.

Researchers have investigated some of the underlying conditions in which these risk factors manifest. For example, Richards (2004) found that motivators for truck drivers to use drugs included fatigue, peer pressure, wanting to fit the trucking 'image', socialisation, relaxation and addiction. Also, Kemp et al., (2013) found that time pressures can lead to physical fatigue and emotional exhaustion, which in turn leads to negative attitudes about compliance with hours of service regulations. These analyses help us to understand why crashes occur and go deeper towards finding the root causes of serious truck crashes – although not deep enough. The “why” question needs to be extended even further. Why, for example, do drivers feel excessively time-pressured? Why do truck drivers feel the need to take drugs?

Whether working as an employee or contractor, truck drivers, like other workers, try to optimise their financial benefit through choices they make about their work practices. The method of driver payment influences the extent to which drivers engage in elevated risk behaviours. A study in the US found that unregulated hours of work and unpaid

non-driving work (such as loading, unloading or waiting for loads) provide incentives for drivers to work longer hours and risk fatigued driving (Arboleda et al., 2003).

The way in which drivers are remunerated influences the likelihood of unsafe behaviours and crashes. Six studies from the 1990s to 2014 are reflected in [Table 2](#) and provide evidence of how pay methods affect drivers’:

- self-imposed time pressures
- use of stimulant drugs
- speeding
- fatigue
- truck maintenance and safety checks

Productivity-based pay is found to produce incentives to drivers to self-impose time pressure, take stimulants, speed and work excessive hours. Productivity pay also predicts driver fatigue and encourages drivers to risk fatigue, poorly maintain trucks and skip safety checks.

In a survey of 573 US motor carrier drivers in 1997, Monaco and Williams (2000) found that hourly payment for drivers had a 10.2 percent lower crash risk compared with productivity pay, i.e. when drivers are paid by the mile or as percentage of revenue earned by the company. Moreover, where drivers are paid mileage rates, a \$0.10 increase in the rate results in a 1.76 percent reduction in the risk of crashing.

In 2003, the National Transport Commission in Australia recognised that there are more entities that influence safety risks in the transport industry introduced a proposal for transport reform. Australian transport law now assigns responsibility to each entity or person in the chain of work involved in delivering goods where their actions or inactions can influence safety in the process.

Police and road authorities can now charge and prosecute employers of truck drivers, customers, loaders and others in the event that their action(s) put drivers at an elevated risk of crashing.

A major inquiry into safety in the Australian trucking industry received submissions from industry experts and researchers who consistently advised that intense competition, industry tendering practices, low freight rates and pressure from clients were probably the most fundamental source of dangerous practices in the industry (Quinlan, 2001). Part of the Inquiry entailed a survey of drivers (n = 300), whose results indicated that there is a range of physical and psychological health afflictions, as well as low-level occupational violence, that are disproportionately reported by truck drivers. Further, owner-drivers were affected with more prevalence and severity.

However, despite the introduction of Chain of Responsibility legislation in Australia under the *Heavy Vehicle National Law Act 2012* to ensure that the driver is not always the only one to carry responsibility for a truck crash, investigations are still not conducted to find the underlying causes of these crashes. Because of this, safety improvements in this sector are not comparable to improvements in aviation and other industries (Cikara et al., 2021). It is noted here that government and industry both have a responsibility for assuring safety in transport. Figure 4 depicts those within the chain who may be held accountable

Table 2. Effects of Driver Payment Methods on Risk Behaviour

Author, Year	Study focus	Method/sample	Findings
Golob & Hensher, 1994	Effects of driver pay system on propensity to speed, self-impose tight schedules, take stimulant drugs	Cross-sectional survey n = 402 Australian truck drivers	- Drivers try to optimise money earned by self-imposed time pressure, leading to use of stimulants, leading to speeding 79% are paid based on productivity
Hensher & Battellino, 1990	Effects of driver pay method on propensity to speed	Cross-sectional (pilot) survey n = 46 Australian truck drivers	- Non-drug users drive 20 km/h slower than drug users - Drivers paid on a percentage of truck earnings drive 15 km/h faster
Williamson et al., 2001	Effects of productivity-based payment on driver fatigue	Cross-sectional survey n = 1,007 Australian long haul truck drivers	Drivers paid by amount of work done report fatigue more often than drivers paid by the amount of time they worked
Arboleda et al., 2003	Effects of compensation methods on driver fatigue risk	Cross-sectional survey n = 116 US trucking companies	Unregulated hours of work and unpaid non-driving work provide incentives for drivers to work longer hours and risk driver fatigue
Williamson, 2007	Effects of payment methods on drug use	Re-analysis of 2 Australian surveys 7 years apart n=970 & n=1007	Drivers paid by productivity were 2-3 times more likely to use stimulant drugs
Williamson & Friswell, 2013	Effects of payment methods and unpaid tasks on driver fatigue	Cross-sectional survey n = 475 Australian truck drivers	Incentive based payment and unpaid waiting times predict driver fatigue
Thompson & Stevenson, 2014	Effects of payment methods on driver fatigue	Cross-sectional survey n = 346 Australian truck drivers	Performance based pay encourages drivers to keep driving at the expense of sleep and rest, maintenance and safety checks

in the transport sector. However, this legislation does not apply to the private sector.

Performance Measurement in Road Safety

Performance measures have long been the mainstay of monitoring healthcare both for the individual and as a system. These range from the traditional thermometer and monitoring of oxygen, cholesterol and blood pressure levels to the more sophisticated scans and assessments for radical treatment and life expectancy predictions. Indicators are used by health professionals to screen for disease, predict adverse outcomes, and measure clinical outcomes and treatments. Collectively, these statistics can be used to establish norms, baseline data, mortality rates and information for national and international comparisons.

High quality health care demands the need for high quality performance metrics. The demand is to develop, collect and feedback performance data to improve the health of the individual and the system. Frameworks have now been established to assess performance based on health improvement rather than just counting “beans” (costs or statistics). These drive quality-based improvement strategies for efficiency and health care outcomes (Sheldon, 1998). Current indicators evaluate, monitor and control the critical factors that influence the performance. Here a hierarchy of key performance indicators (KPIs) consider the human factors, technology and medication (Burlea-Schiopoiu & Ferhati, 2020). There is a need for similar monitoring to track and assess the effectiveness of road safety reform.

Traditional road safety and performance indicators have focused on the higher-level risk factors of fatalities per 100,000 population, injuries per 100,000 population and

crash statistics for country comparisons and benchmarking within jurisdictions. These have expanded to include a range of behavioural risk indicators such as speeding, impairment, distractions and fatigue as well as motor vehicle (e.g., age, roadworthiness, fleet composition and star ratings), road risk assessments and gradings (such as road safety audits and iRAP) and environmental components including traffic volumes. New insights can be gained when a road safety index is composed of all risk indicators (Shen et al., 2010). However, these risk factors and indicators need to be coordinated with a deeper monitoring and analysis of any countermeasures.

Safety performance indicators developed into a road safety performance index can now be used to identify strengths and weaknesses of a country's road safety system and more precisely define goal-oriented actions (Tešić et al., 2018). A comprehensive approach to monitoring safety performance indicators has been adopted in Serbia to assisting the achievement of road safety strategies, plan activities and allocate funds (Pešić & Pešić, 2020). Risk specific in-depth indicators can also be developed to allow for industry-wide monitoring of commercial motor vehicle drivers, allowing comparisons and rankings of transportation companies for levels of road safety from the aspect of driver fatigue (Davidović et al., 2020). Notably, these performance indicators are confined in their development and application and not generically adopted within the Safe System approach.

The adage, prevention is better than cure, is a fundamental principle of health care and should be applied equally to road safety. Lessons can be learned from the WHS sector and health care system in applying a more stringent approach to road safety KPIs in a more hierarchical application of importance determined by their productivity outcomes. The deficiency in road safety is not the lack of available source indicators, rather the failure to harness and analyse those indicators to drive road safety management reform.

System Approaches to Improving Road Safety

There have been important developments in recent years to develop a systems-focused crash data analysis more like the root cause analysis approach taken in some sectors (McIlroy et al., 2021; Salmon et al., 2020). This type of analysis delves into the foundational crash causes to critically identify reform actions as prevention focused initiatives addressing the higher-order factors and continually asking why in the investigative approach.

Discussion

Road and traffic systems are largely managed by government authorities. They provide road infrastructure, set rules and standards and enforce these rules and standards. Their safety management performance is measured mainly at the outcome level, that is, the number of road deaths and injuries that occur in their jurisdictions. Rarely are KPIs and

intermediate performance indicators used in assigned responsibilities and accountabilities for the various agencies. This is particularly relevant to the integration of strategies. Traditionally, research and evaluation of specific interventions to improve the safety of the vehicles, road environment and road user behaviour have guided best performing jurisdictions on good practice. Using evidence-based interventions has certainly reduced road trauma over time.

However, a commitment to eliminate road trauma, as prescribed in the Safe System approach, calls for smarter ways to understand the processes of road injury. Understanding that the road system and its consequential use involve continual and dynamic interactions between system components will be necessary to meet the ambitions of the Safe System.

Enhancing the static approach of collecting data on road, motor vehicle, and human risk factors, then implementing known-to-be-effective countermeasures, potentially boosts the likelihood of meeting ambitious goals for a Safe System. This will inevitably require a lot of work towards understanding the specific system interactions to find ways to better manage large, multi-component road/traffic systems. To do this, road safety researchers and practitioners will need to move beyond the traditional static or linear ideas of how road injury occurs to new dynamic systems-based injury epidemiology models.

This will necessitate developing and utilising collaborative processes with diverse disciplines and sectors to better understand the interconnected factors shaping road safety problems and support discussions about the potential solutions that align with a Safe Systems approach (Naumann et al., 2020).

The application of 'systems' thinking is currently predominantly directed towards the road network and infrastructure and vehicle controls, with minimal attention focused on addressing the systems, inherently present in the failings of human behaviours. Here the tendency is to use motor vehicle technology to compensate for these human failings and illegal behaviours (e.g., alcohol interlocks, speed limiting devices, anti-lock braking, frontal protection systems, electronic stability controls, lane departure alerts, and fatigue monitoring alerts). While these are important safety advancements, and will continue to the 'driverless car', solutions based on systems thinking as to why drivers continue to drink and drive, speed, are distracted or drive while fatigued are limited in road safety reform. The human factor is critical component for safe operations. In a practical perspective, we are still 'wallpapering over the cracks in the wall' or masking the symptoms as remedial action, rather than curing the real cause. Therefore, safer technology with safer behaviours is the winning combination for safe transportation (Molan & Molan, 2021).

Leveson (2011), describes in-depth analysis of human error fundamentals as commissions and omissions due to slips or mistakes in intention(s). Within the road safety spectrum, illegal and critical risk activities such as drink driving, dangerous driving, and speed dangerous are conscious and deliberate actions and not errors. Here, 'sys-

tems' thinking and root cause analysis must play a vital role in the strategies for reform.

Complementing the 'why' factor in root cause analysis, the key question to be answered in every crash investigation, is 'How can the risk of a crash of this nature be prevented in the future' (Shuey & Myers, 2021). This must be mandated in all police crash reporting. Introducing these imperatives will assist in directing road safety reform and ultimately save lives.

Conclusions

The scientific model, Haddon's Matrix, has served practitioners well in focusing road safety efforts to address contributing factors in injury and fatal crashes. However, a systems-focused approach is needed if we are to achieve zero road trauma. We are currently not achieving enough impact on latent risk conditions which are fully inherent in the road traffic and human behavioural environment. There is an urgent need to maximise root cause analysis and contributory factors to identify and eliminate these systemic risks. To achieve this, we can learn from the analyses models in the medical, aviation and occupational safety sectors.

A merging of occupational and road safety models can be observed in the transport industry where there are shared responsibilities between governments and companies. The heavy vehicle transport sector is an area of road use where some efforts have been made to address key risk factors such as speeding and driver fatigue. However, neither governments nor transport companies are going far enough in ameliorating the endemic risk factors for all road users on public roads.

While the road and traffic system is not as controllable as a confined workplace, it is time to apply some of the more advanced system analysis methods to understanding systemic risk factors and root causes of injury in this sector. This holistic and integrated approach will substantially impact upon road trauma reduction.

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