Who’s in control of the fatal five? A systems analysis of Queensland’s road transport system

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Abstract

Despite significant progress, road transport systems continue to kill people on a scale that is comparable to cancers, cardiovascular disease, and respiratory diseases. In Queensland (Qld), Australia, there is currently a targeted focus on reducing the ‘fatal five’ behaviours underpinning road trauma. Although progress is being made, researchers have argued that a new systems thinking approach is required in order to create more significant safety gains. This paper describes a study that used the STAMP systems analysis methodology to develop a control structure model of the road transport system in Qld. The control structure model depicts the actors/organisations within the Qld road transport system (e.g. road users, road designers, vehicle manufacturers, road safety authorities, research groups, government agencies, advocacy groups) along with the control relationships that exist between them. The analysis depicts a shared responsibility for the fatal five behaviours, and shows that, compared to other safety critical domains, there are less formal control structures and that opportunities exist to add new controls and strengthen existing ones. Further, current crash analysis systems are brought into question by the model. In closing the practical implications for road safety interventions are discussed.

Introduction

There is no doubt that significant progress has been made by the road safety community in its attempts to reduce road trauma. Indeed, in most areas roads are now the safest they have ever been. Despite this, the facts around current and projected levels of road trauma still make for sobering reading: in 2012 road injury was the ninth leading cause of worldwide deaths and it is estimated that it will be the fifth leading cause of deaths by 2030 (WHO, 2011; 2014).

This continuing burden is unacceptable. Recently researchers have suggested that a new systems thinking approach is required in order to achieve new reductions in trauma (e.g. Salmon and Lenne, 2015). This argument is based on the success of systems thinking approaches in other safety critical systems and on the notion that the current road safety approach does not sufficiently consider the complex sociotechnical nature of road transport systems. This is despite confirmation that road transport systems do display all of the characteristics of complex sociotechnical systems (e.g. Larsson et al, 2010; Salmon et al, 2012).

Traditionally road safety efforts have involved a focus on one component of the problem (e.g. driver behaviour) and an attempt to improve performance of that component (i.e. make drivers more compliant). This is currently exemplified in Queensland by the focus on the fatal five behaviours that create road trauma: speeding, drink and drug driving, failure to wear a seatbelt, driving while fatigued, and distraction and inattention. The prevalent approach to limiting road trauma involves attempting to prevent drivers from engaging in the fatal five behaviours through driver-centric measures such as education and enforcement.

In recent times this component approach has received criticism. For example, it has been argued that the inherent complexity in transportation systems and the multitude of factors shaping behaviour have not been fully considered (Cornelissen et al, 2015; Larsson et al, 2010; Salmon et al., 2012; Salmon and Lenne, 2015). The consequence is that many factors influencing behaviour may be left untouched, diminishing the effectiveness of road user focussed interventions such as education and enforcement (Larsson et al, 2010; Salmon et al., 2012). An absence of systems thinking in system and countermeasure design is now widely acknowledged to represent a key issue in safety critical systems (e.g. Dekker, 2011; Reason, 1997).

Accidents are known to be emergent properties of complex sociotechnical systems; that is, factors from across the overall 'system' interact to create them (Dekker, 2011; Leveson, 2004; Rasmussen, 1997). Road transport is a complex sociotechnical system, comprising many inter-related components (Larsson et al, 2010; Salmon et al, 2012), yet the role of factors outside of road users, vehicles and the road environment in road trauma remains unclear. Notably, there is limited information regarding the systemic factors that interact to create the fatal five behaviours. The growing complexity of road transport systems may have outpaced our understanding of what they comprise, of what factors interact to create road trauma, and of how to make them safer.

To cope with this complexity, a complex sociotechnical systems approach is required; however, despite being a proven approach to enhancing safety in other domains, this is only beginning to gain traction in road safety circles (Salmon and Lenne, 2015). As a first step in initiating a systems thinking approach to road trauma, Larsson et al (2010) and Salmon et al (2012) identified the need to use complex system modelling approaches to describe road transport systems and the interrelations between entities within them. Similarly, Salmon and Lenne (2015) argued that such approaches should be applied during road system analysis efforts. This paper is a direct response to this, presenting a Systems Theoretic Accident Model and Process method (STAMP; Leveson, 2004) control structure model of the road transport system in Qld, Australia. The aim of the exploratory study was to delineate the range of actors and organisations within the Qld road transport system along with the key relationships that exist between them.

Method

The control structure component of STAMP (Leveson, 2004) was used to construct a model of the Qld road transport system. STAMP is an accident model and analysis method that views accidents as resulting from the inadequate control of safety-related constraints (Leveson, 2004), arguing that they occur when component failures, external disturbances, and/or inappropriate interactions between systems components are not controlled (Leveson, 2004; 2011). Leveson (2004) describes various forms of control, including managerial, organisational, physical, operational and manufacturing-based controls. STAMP uses a 'control structure' modelling technique to describe complex systems and the control relationships that exist between components at the different levels. A taxonomy of control failures is then used to classify the control failures that played a role in the incident under analysis. An additional component of STAMP involves using systems dynamics modelling to analyse the behaviour of the system over time. This enables the interaction of control failures to be demonstrated along with their effects on performance. Whilst the method has typically been used for the analysis of large-scale catastrophes, the control structure component is useful in isolation as a systems modelling tool (Salmon et al, 2012).

Initially two researchers constructed the control structure model based on various sources, including road system documentation (e.g. road rules and regulations, road safety strategies, policy documents), stakeholder websites (e.g. Transport and Main Roads Queensland website), and the academic literature. Following this, a third analyst then reviewed the model and provided feedback. All three analysts then met and worked through the model until all were in agreement regarding its structure and components. The model is currently being validated via a Delphi study involving road safety experts, systems thinkers, and complex system modelling experts, however this has not yet been finalised and so the results are not reported here. The final validated model will be included in the conference presentation.

Results

STAMP control structure model of Qld road transport system

A generic STAMP control structure model is presented in Figure 1. The control structure model incorporates two components: the control structure for system design and development, and the control structure for system operation. In the present analysis, both control structures were developed; however, due to space constraints only the control structure for system operation is discussed.

The system operation control structure model of the Qld road transport system is presented in Figure 2.

Within Figure 2, the downward flowing arrows and text linking the higher levels to the lower levels represent control mechanisms imposed by actors and/or organisations at the level above on actors and/or organisations at the level below. For example, Police officers at level 4 of the model impose control on the road users at level 5 via monitoring, enforcement and penalties. Likewise, at level 1 national and federal parliaments impose control on the level below (government agencies, industry associations, user groups and the courts) through national policy.

As noted previously, control can be achieved in various ways including through managerial, organisational, physical, operational and manufacturing-based controls. That is, behaviour is controlled not only by engineered systems and direct intervention, but also indirectly by policies, procedures, shared values, and other aspects of the organisational culture. It is notable that there is a mixture of control types shown in the draft control structure. Finally, it is worth noting that control mechanisms might exist between non-adjacent levels (as represented by curved arrows). For example, at level 3 Transport and Main Roads Queensland imposes licensing and registration controls on road users at level 5.

The dashed arrows flowing upward through the model in Figure 2 represent feedback mechanisms whereby actors/artefacts/organisations provide information regarding the status of the system to those higher up in the system. This is a key component of system functioning and enables higher levels to understand how the system is operating at the lower levels, which in terms informs decision-making. For example, 'Government reports' are a feedback mechanism provided by Level 2 (government agencies, industry associations, user groups and the courts) to Level 1 (parliament and legislatures). At the lower levels of the system, crash reports are provided to Police officers (Level 4) by road users (Level 5) who were either involved in the crash or witnessed the crash. As with the control relationships, feedback relationships may exist between adjacent levels of the control structure (shown by straight dashed arrows) or they may exist between non-adjacent levels (shown by curved dashed arrows).

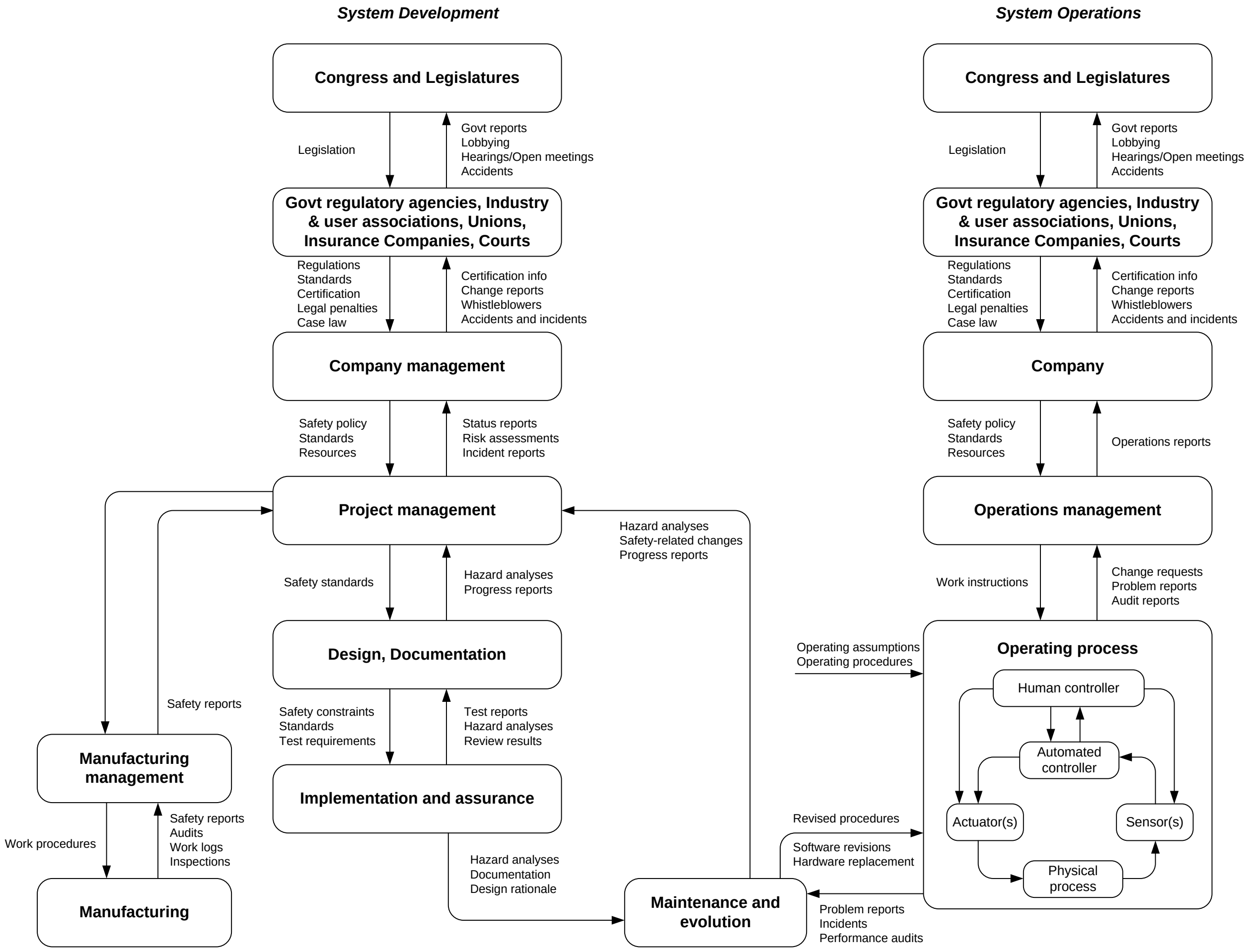

Figure 1. Generic control structure model

An overview of each level in Figure 2 is given below.

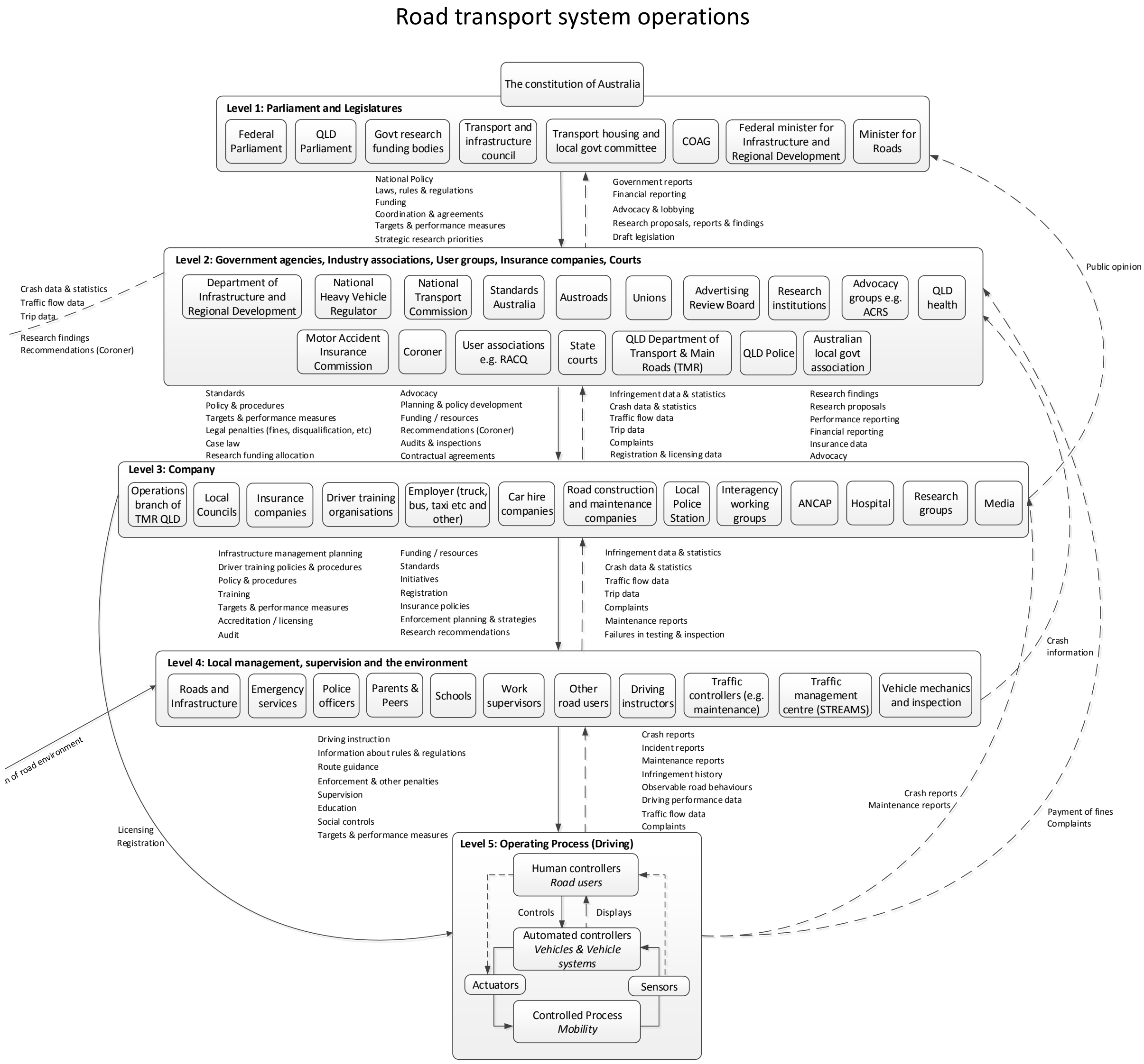

Figure 2. Control structure model of Qld road transport system (note the connections from the left hand side represent those from the road system design control structure)

Level 1 Parliament and Legislatures

Level 1 of the control structure represents the highest level of the Qld road transport system, comprising both federal and state governments and related agencies. At the top of this level sit the Constitution since it has the power to legislate for different aspects of road transport. Underneath the Constitution sit the state and federal parliaments, Ministers with transport portfolios, government committees and councils (including COAG – Council of Australia Governments) and federal research funding bodies (such as the Australian Research Council and the National Health and Medical Research Council).

Key control mechanisms enacted by this level include national policy (e.g. the National Road Safety Strategy 2020), laws, rules and regulations, funding for activities such as infrastructure management, road safety initiatives and research, coordination and agreements (e.g. the COAG inter-governmental agreement on cost shifting), targets and performance measures (e.g. road safety targets), and strategic research priorities.

The feedback mechanisms coming into this level include government reports covering issues such as the road toll and research findings, financial reporting, advocacy and lobbying, research proposals, and draft legislation.

Level 2: Government agencies, industry associations, user groups, courts

Level 2 of the control structure comprises government agencies, regulators, industry associations, user groups, and the courts. Actors and organisations represented at this level include federal and state government departments and statutory bodies, safety regulators, user and industry associations and courts, state Coroners and regulators such as the Motor Accident Insurance Commission (who regulates the compulsory third party insurance scheme in Qld) the Qld Police and National Heavy Vehicle Regulator.

There are various forms of control enacted by those at level 2 on actors and organisations at level 3, including standards (e.g. Australian Design Rules), road transport policies, procedures and codes of conduct (e.g. transport infrastructure asset management policy), targets and performance measures, legal penalties, case law, research funding, planning and policy development, funding and resources, coronial recommendations, audits and inspections, and contractual agreements (e.g. road maintenance contracts).

There are various feedback mechanisms informing level 2 about road transport system performance. Key mechanisms from level 3 to level 2 include reporting around infringements, crashes, fatalities and injuries, traffic flow and trips, financial performance, and registration and licensing. In addition, a key feedback mechanism for level 2 is research findings, whereby research groups provide reports and presentations to key road safety bodies such as Transport and Main Roads (TMR) Qld. Finally, insurance claims data is also fed up to the Motor Accident Insurance Commission by insurance companies

Level 3: Companies

The company level of the model includes organisations who are engaged in key road transport operations tasks such as licensing and registration, employment of professional drivers, and the allocation of safety ratings. In addition, research groups and the media are included at this level. These actors and organisations include the operational divisions of TMR, various employers of professional drivers, including freight organisations and public transport providers, ANCAP, hospitals, and road safety research groups such as the Centre for Accident Research and Road Safety (CARRS-Q).

The actors and organisations at level 3 enact the most number of control mechanisms within the model. Some of the key control mechanisms enacted on level 4 include infrastructure management planning, training (e.g. for professional drivers and driving instructors), policy and procedures around driver training and employment (e.g. working hours within freight organisations), accreditation and licensing (e.g. accreditation of driving instructors), registration, insurance policies, and road auditing. A key control mechanism enacted on level 4 is initiatives, which cover local initiatives developed with the specific aim of improving road safety (for example drink driving blitzes, education programs etc.).

The actors and organisations situated at level 4 in the model use a range of feedback mechanisms to update those at level 3. The feedback mechanisms used provide information regarding infringements, crashes, fatalities and injuries, traffic flow, and trips. In addition, complaints made to employers and local councils regarding safety issues provide a key feedback mechanism between levels 4 and 3, which in turn inform activities such as the development of initiatives. Finally, maintenance and inspection reports provide a key mechanism for level 3 actors and organisations to understand the condition of roads and vehicles.

Level 4: Local management, supervision and the environment

Level 4 in the control structure represents the road environment and the actors and organisations that either supervise or influence road user behaviour. This includes the road and road infrastructure, which comprises the road, road signage, road markings and road infrastructure such as traffic lights, roundabouts and median strips. The Police provide a key role at this level, effectively supervising road user behaviour, enforcing road rules and regulations, and providing a traffic control function when necessary. The emergency services are included as providing control mechanisms in the event of a road crash. Additional supervisory controls are provided by parents and peers, schools, and workplace supervisors (for professional drivers). Other important actors at this level include other road users (due to their influence on road user behaviour) and driving instructors. Traffic control mechanisms are facilitated by traffic management centres, which monitor traffic behaviour work with the police, emergency services, road maintenance organisations, and public transport providers to maintain network flow. Finally, vehicle mechanics provide critical control functions related to road vehicles.

The control mechanisms enacted by those at level 4 relate specifically to control of road user behaviour. The roads and road infrastructure provide information regarding road rules and regulations (e.g. speed limits) and route guidance, whilst the police officers enforce the road rules through monitoring and measuring road user behaviour (e.g. speeds), alcohol and drug testing, and issuing warnings and fines. Supervisory controls, such as monitoring driver behaviour, providing feedback on performance, and educational activities are enacted by parents, workplace supervisors, and schools. Finally, mechanics and vehicle inspectors ensure that road vehicles are performing to the standards required by road licensing rules and regulations.

The primary feedback mechanism coming into level 4 is offered by road users who provide specific information regarding road user behaviour and road system performance. These include crash reporting (e.g. driver statements to police and emergency services), incident reporting (e.g. drivers reporting to work supervisors regarding near miss incident), maintenance reports and infringement histories. Further important feedback mechanisms between levels 5 and 4 are observations of road user behaviour and driving performance and traffic flow data held by road cameras and traffic management centres.

Level 5: Operating Process (Driving)

The final level in the model incorporates vehicles and their human operators. At this level the driver exerts control over the vehicle and the vehicles systems provide feedback about the status of the vehicle and vehicle performance.

Discussion

The aim of this paper was to present a STAMP control structure model of the Qld road transport system. The analysis presented was undertaken in response to recent calls for a systems thinking approach to road transport system analysis (e.g. Larsson et al, 2010; Salmon and Lenne, 2015). A first step in initiating such an approach involves describing the range of actors and organisations that make up road transport systems along with the relationships that exist between them. This contribution will enable some of the interactions that give rise to emergent behaviours, such as the fatal five behaviours, to be described. The control structure model presented depicts the range of actors and organisations operating within Qld and outlines some of the key control and feedback relationships between them.

The model supports the perspective that the fatal five are a systems problem, as opposed to merely a driver problem. This is evidenced by the myriad actors and organisations that influence how the road transport system operates – driving occurs within a complex sociotechnical system in which the decisions and actions of many have an influence on behaviour. In line with systems thinking it may be more appropriate to treat the fatal five behaviours as *consequences* rather than *causes*. That is they may be the consequence of issues within the road transport system, and indeed wider society. This provides a different perspective and potentially offers different avenues when developing road safety interventions. A challenge for road safety research is to identify the issues than can be managed through road safety interventions.

A further contribution of the model is further clarification around who shares the responsibility for road trauma and the fatal five behaviours in Qld. The shared responsibility for road trauma is now widely accepted across Australian jurisdictions and attempts have been made to identify those responsible for road safety. Few, however, have gone beyond the major actors and organisations to describe who shares the responsibility across road transport systems, or to clarify what the responsibility entails in terms of core activities and behaviours. By detailing the range of actors and organisations involved in road system operation in Qld, the control model structure takes a step towards this. First, the actors and organisations are described, and second, the key roles that they play can be inferred by the control relationships and feedback mechanisms described. It can be concluded from this that a diverse set of actors and organisations share the responsibility for the fatal five behaviours and road trauma in Qld, covering the Constitution and government, government agencies, unions, research institutions, local government, road safety authorities, insurance groups, driver trainers, advocacy groups, the police and emergency services, road users, parents and peers, and schools to name only a few. Notably, there are others involved in the design of road systems not described in Figure 2; however, the additional road system design control structure developed by the authors covers these actors and organisations. Key future research requirements involve examining actors' and organisations' perceptions regarding their roles and responsibilities in road safety along with the range of activities that they undertake to fulfil this. In turn, this will highlight further control and feedback mechanisms to add to the model. A final implication of this finding is that interventions designed to improve behaviour and performance may also be fruitful when aimed at the higher levels of the road transport system. For example, improved performance and interactions at the higher levels of the system around policy development and implementation will have positive effects at the lower levels.

An interesting aspect of the model is the different forms of control mechanism described. Leveson (2004) describes various forms of control, including managerial, organisational, physical, operational and manufacturing-based controls. Although STAMP was developed for more typical process control-based systems, it is interesting to note that all of forms of control outlined by Leveson (2004) are extant in the Qld road transport system (although manufacturing-based controls are present only in the road transport system design control structure not presented in this paper). For example, managerial and organisational controls are present through the government at the higher levels of the system and also organisations who employ professional drivers. Whilst the higher levels are characterised by managerial and organisational controls, the lower levels require more physical controls in the sense that road users need to be controlled when operating on the road. For example, vehicles and the road infrastructure provide physical control over road users in terms of where they can go, who they can interact with, and how fast they can travel. In turn, road users provide physical control over vehicles and indeed other road users. Operational controls are provided by Police officers and road rules and regulations.

A final interesting feature of the model is the relative strength of the controls described, particularly when road transport is compared to other more heavily regulated transport systems such as aviation and rail. Despite ostensibly similar controls enacted across the different transport systems, it is apparent that some forms of control are weaker within road transport and consequently that there is more latitude for behaviour. For example, controls around driver impairment are stronger in areas such as civil aviation, whereby pilots have to comply with strict rules around alcohol consumption and are often tested for alcohol before flying the plane. Although road users are bound by rules and can be tested via random breath testing, the nature of the road transport system is such that the controls around alcohol are weaker and there is more latitude for road users to drive under the influence. Consequently drink driving continues to be a prominent factor in road trauma. The same can said for the other fatal five behaviours, (fatigue, speeding, distraction, failure to use seat belts) whereby other transportation systems have stronger more effective controls for similar issues through rules and regulations, performance monitoring, and procedures. A challenge for the road safety community is to strengthen the controls and influences enacted on road users whilst at the same time ensuring that they are practical to enact and do not become overly intrusive. It is likely that this will involve new forms of control rather than attempting to simply increase the frequency within which existing controls are enacted through avenues such as more random breath testing and more monitoring of road user behaviour and speeds. Rather, new approaches to preventing the fatal five behaviours may be required. The program of research from which this article derives is focussed on this line of inquiry.

In terms of practical implications, the control structure model raises questions regarding current road crash data collection and analysis systems. As discussed, the model depicts a vast range of actors and control relationships that share the responsibility for road trauma by designing and operation the road transport system. Underpinned by systems thinking, the analysis suggests that interactions between these actors and organisations can play a role in creating or enabling the fatal five behaviours and road trauma. In discussing road crashes, Salmon and Lenne (2015) modified Rasmussen's (1997) key tenets of systems thinking to apply to road transport systems. It was argued that road crashes are emergent properties impacted by the decisions and actions of all actors within the road system, not just by the road users alone. Likewise, the modified tenets suggest that threats to road safety are caused by multiple contributory factors rather than a single poor road user decision or action. Finally, it was suggested that threats to road safety result from poor communication and feedback across levels of the system. In light of these modified tenets and the control structure model, it is questionable whether current data collection and analysis systems are sufficiently identifying the contributory factors involved in road trauma. Even with the most in-depth crash systems, the knowledge base on the causes of key road crash causing behaviours is heavily oriented to contributory factors around drivers, their vehicles, and the road environment, with little information regarding less direct contributory factors residing at the higher levels of the system. The key to identifying these higher level contributory factors lies in examining the relationships and interactions between the actors and organisations residing at the higher levels of the road system. The development of systems thinking-based crash data collection and analysis systems is a key future research requirement that has previously been articulated (e.g. Salmon and Lenne, 2015) and further emphasised through this study.

As a first of its kind application in road safety the analysis revealed important methodological limitations when STAMP is applied in this context. One interesting feature of the control structure is the fact that many of the mechanisms identified may not in-fact represent controls per se, rather they may be closer to influencing factors. This finding is currently being explored further by the authors and could potentially lead to an extension to the STAMP method whereby differentiation is made between controls and influencing factors. A second limitation of the model relates to its inability to represent some of the wider societal influences on road user and road system behaviour. Ostensibly such influences represent key drivers underpinning the fatal five behaviours; however, the focus on control and feedback mechanisms ensures that it is difficult to incorporate such influences in the model. It is proposed that this provides one avenue for methodological development that will enhance the utility of STAMP in the road transport context.

It is worth noting that the model presented is in draft form, and that a Delphi study is currently being completed to refine and validate the model. This involves ascertaining road safety and systems thinking experts' feedback on the model. As such, issues surrounding debates over the placement of actors and organisations at different levels will be resolved. Notwithstanding this, further research clarifying the placement of actors and organisations in the model is recommended. Moreover, an additional line of inquiry involves examining explicitly the functions and systems in place, as opposed to merely the actors and organisations implementing them. Whilst the intention was to represent such functions through the control mechanisms between levels, it is acknowledged that further details will prove useful.

In closing, it is hoped that the systems thinking approach continues to gain traction in road safety circles. Applications continue to emerge in the literature and the findings are compelling (e.g. McClure et al, 2015; Newnam and Goode, 2015). Further applications of systems thinking in the road safety context are encouraged. It is these authors opinion that the rich outputs from such applications will support the optimisation of road transport systems along with the attainment of further road safety gains.

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