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Who is in control of road safety? A STAMP control structure analysis of the road transport system in Queensland, Australia

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ABSTRACT

Despite significant progress, road trauma continues to represent a global safety issue. In Queensland (Qld), Australia, there is currently a focus on preventing the 'fatal five' behaviours underpinning road trauma (drug and drink driving, distraction, seat belt wearing, speeding, and fatigue), along with an emphasis on a shared responsibility for road safety that spans road users, vehicle manufacturers, designers, policy makers etc. The aim of this article is to clarify who shares the responsibility for road safety in Qld and to determine what control measures are enacted to prevent the fatal five behaviours. This is achieved through the presentation of a control structure model that depicts the actors and organisations within the Qld road transport system along with the control and feedback relationships that exist between them. Validated through a Delphi study, the model shows a diverse set of actors and organisations who share the responsibility for road safety that goes beyond those discussed in road safety policies and strategies. The analysis also shows that, compared to other safety critical domains, there are less formal control structures in road transport and that opportunities exist to add new controls and strengthen existing ones. Relationships that influence rather than control are also prominent. Finally, when compared to other safety critical domains, the strength of road safety controls is brought into question.

1. Introduction

The impact that road safety communities worldwide have had on reducing road trauma is without question. However, current and projected levels of road trauma confirm that road crashes continue to represent a problem with outcomes that are comparable to other major public health issues such as cancer, and cardiovascular and respiratory diseases (WHO, 2011, 2014). Notably, it is a problem that is forecast to become greater in many areas (WHO, 2014). In response to this, a growing body of researchers and practitioners have argued that a new systems thinking approach may be one way of achieving new and ambitious road safety targets (Larsson et al., 2010; Salmon and Lenne, 2015; Read et al., 2013). Central to this argument is that current deterministic approaches to the problem do not fully consider the inherent complexity in transportation systems or the full range of factors shaping behaviour (Cornelissen et al., 2015; Larsson et al., 2010; McClure et al., 2015; Salmon et al., 2012; Salmon and Lenne, 2015). For example, existing research has focussed on either parts in isolation, such as drivers (e.g. Stephens and Fitzharris, 2016) or pedestrians (e.g. Dommes et al., 2015), or a particular component of the road trauma problem such as text messaging while driving (He et al., 2016) or perceptions of speeding (Knight et al., 2013). Such applications have their place, particularly in support of targeted interventions; however, systems thinking proponents argue that specific road user focussed interventions, such as education and enforcement, may leave many other factors that influence behaviour untouched, which in turn could limit their effectiveness (Larsson et al., 2010; Salmon et al., 2012). Whilst these kinds of interventions have contributed to significant reductions in road trauma in many countries, it is argued that they may have hit a ceiling in terms of effectiveness.

It is important to note here that the systems thinking philosophy referred to above is different to the 'safe systems' philosophy that is currently prevalent in road safety strategies worldwide (e.g. Johansson, 2009; Wegman et al., 2008). Although there are similarities, Salmon and Lenne (2015) discuss the key differences between the two. An absence of systems thinking in accident prevention activities is acknowledged to be a flawed approach to safety management (e.g. Dekker, 2011; Reason, 1997). Emphasising this, applications of systems thinking in other safety critical domains have shed new light on the causes of accidents (e.g. Goode et al., 2014; Newnam and Goode, 2015; Salmon et al., 2013; Zhang et al., 2016). More generally, a review of 134 studies involving applications of sociotechnical systems theory found that almost

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90% reported improvements in safety (88%) and productivity (87%) (Pasmore et al., 1982).

Based on successful applications such as these, it is argued that a more holistic consideration of road transport systems and the factors underpinning road user behaviour and road trauma will support the development of new interventions that focus upon aspects beyond the behaviour of road users (e.g. policy, road safety strategies, design standards and guidelines). Early applications underpinned by systems thinking have confirmed that such an approach is applicable in road transport systems (e.g. Cornelissen et al., 2013; Newnam and Goode, 2015; Salmon et al., 2012, 2016) and that it is possible to model road systems and the systemic influences on behaviour and trauma (Goh and Love, 2012; McClure et al., 2015). Although this early work shows promise, studies considering overall road transport systems and the range of factors influencing road user behaviour are sparse.

The need to consider the overall road transport system derives from the notion that crash contributory factors may also reside outside of the 'safe system' elements of road users, vehicles, and the immediate road environment (Salmon and Lenne, 2015). 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 and interaction of factors outside of road users, vehicles and the road environment in road trauma remains unclear. In the Australian context, for example, 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, methods underpinned by complex and sociotechnical systems theory are required to support both analyses of crash-related behaviours and the development of countermeasures; however, such methods are 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) discussed the need to use systems analysis 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 crash and road system analysis efforts. This paper responds to this call by presenting a Systems Theoretic Accident Model and Process (STAMP; Leveson, 2004) control structure model of the road transport system in Qld, Australia. The aim of the analysis was to identify the range of actors and organisations within the Qld road transport system along with the key relationships that exist between them. The intention was to clarify who currently shares the responsibility for the fatal five behaviours and road trauma in Qld, to examine how the responsibilities are currently enacted, and in turn provide a basis for identifying crash contributory factors outside of road users, vehicles, and the road environment. While the analysis presented is based on the Qld system, the structure of road transport systems is sufficiently similar, at least in developed nations, that we expect the findings of the analysis to be broadly generalizable to other jurisdictions.

1.1. STAMP and control theory

STAMP (Leveson, 2004), originally developed as an accident analysis methodology, is underpinned by systems and control theory. The method takes the view that accidents result from the inadequate control or enforcement of safety constraints; when disturbances, failures, or dysfunctional interactions between components are not handled by existing control systems (Leveson, 2004). In the road safety context, for example, the model might suggest that accidents relating to drink driving (or drunk driving in the US) occur when controls such as Blood Alcohol Testing (BAC), driver penalties, and education campaigns fail to stop drivers from driving under the influence. STAMP therefore views safety as an issue of control and one that is managed through a control structure that has the goal of enforcing constraints on actors within the system. The STAMP methodology was developed to support analysts in identifying what controls exist and where particular controls were ineffective in a particular incident.

Leveson (2004) describes various forms of control, including managerial, organisational, physical, operational and manufacturing-based controls. That is, behaviour is controlled not only by engineered systems and direct intervention, but also by policies, procedures, shared values, and other aspects of the organisational culture. The first phase of STAMP involves using a control structure modelling technique to describe the system under analysis and the control relationships that exist between components across its different levels related to both system design and system operation. The control structure model views systems as comprising interrelated components that maintain a state of dynamic equilibrium through feedback loops of control and information (Leveson, 2004). Accordingly, control structure models incorporate a series of hierarchical system levels and describe the actors and organisations that reside at each level. Control and feedback loops are included to show what control mechanisms are enacted down the hierarchy and what information about the status of the system is sent back up the hierarchy.

A generic control structure model is presented in Fig. 1 (Leveson, 2004). The left hand side of Fig. 1 shows a generic control structure for system development whereas the right hand side shows a generic control structure for system operation. The arrows flowing down the hierarchy represent control relationships (or reference channels, Leveson, 2004) and the arrows flowing up the hierarchy represent feedback loops (or measuring channels, Leveson, 2004). In relation to the drink driving example described above, the Police would enact the control of 'random BAC testing' on road users. In turn, BAC level would represent a form of feedback between drivers and Police officers, and in turn statistics regarding the number of positive and negative BAC tests would be communicated to those at the higher levels of the system to enable road safety authorities and policy makers to assess whether current controls are having the desired impact.

Once the control structure is developed it can be used to support various analyses. For example, for accident analysis purposes a taxonomy of control failures is applied to identify and classify the control failures that played a role in the incident under analysis (see Leveson, 2004). Alternatively, the control structure can be used in risk assessment efforts to identify points of weakness or potential hazards within the system. An additional but less commonly used component of STAMP involves using systems dynamics modelling to analyse the behaviour of the system over time. This enables the interaction of controls, control failures and feedback loops to be demonstrated along with their effects on behaviour. Whilst the method has typically been used for the analysis of large-scale catastrophes (e.g. Kim and Nazir, 2016; Underwood and Waterson, 2014), the control structure component is useful in isolation as a systems modelling tool. In the present case study the control structure component was used on its own to demonstrate its utility in providing a description of a complex system, without the need to refer to specific incidents or accidents. The remainder of this article therefore focuses on the control structure for system operations in the Qld road transport system.

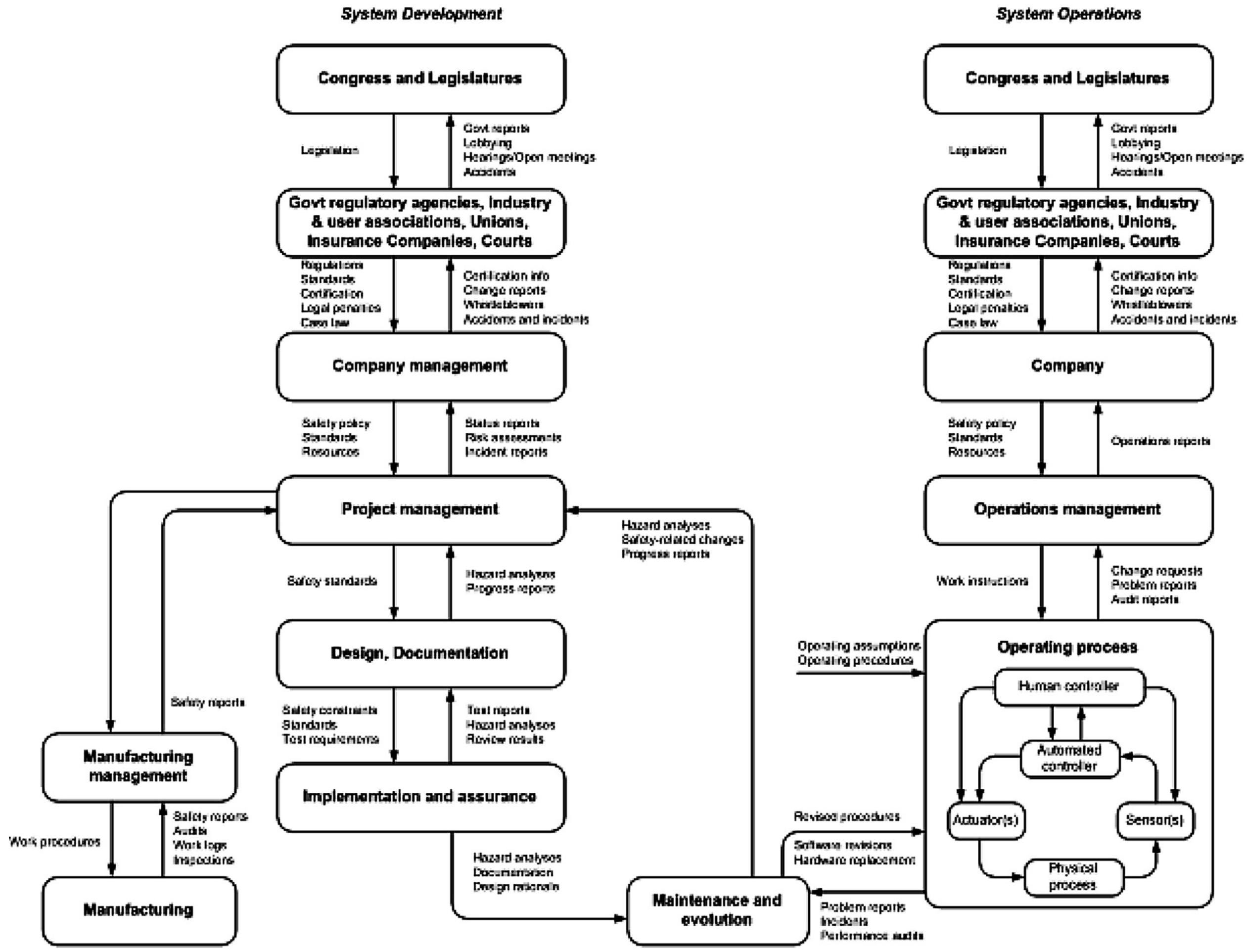

Fig. 1. STAMP generic control structure model.

(Adapted from Leveson, 2004)

2. Methodology

2.1. Qld road transport system control structure development

Initially two researchers constructed a draft control structure model of the Qld road transport system. The process involved:

1. Adapting the STAMP control structure levels shown in Fig. 2 to fit the Qld Road transport system (see Table 1 for descriptions of Qld road transport system levels);
2. Identifying actors and groups who reside at each of the control structure levels; and
3. Identifying the control and feedback loops existing between the different control structure levels.

Development of the control structure model was based on information derived from 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 (e.g. Scott-Parker et al., 2015a; Newnam and Goode, 2015). Following this, a third analyst reviewed the model and provided feedback. All three analysts then met and worked through the model until consensus was reached regarding the structure, components and relationships depicted in the model.

2.2. Qld road transport system control structure validation

A final draft of the control structure model was refined and validated via a modified two- round Delphi study (Linstone and Turoff, 1975). The aim of the Delphi study was to gather feedback on the model from appropriate Subject Matter Experts (SMEs), refine the model, and then reach consensus from the SMEs that its contents were valid. Local and international experts in road safety, systems thinking and complex systems modelling were identified from authorship of peer reviewed papers and from professional web profiles. The contact details of 288 potential participants were identified from publicly available sources and these experts were invited to participate in Round 1 of the study.

Forty-four participants (26 males, 18 females) responded to the invitation and completed Round 1. An overview of the participants' demographic information is presented in Table 2. Participants had a mean age of 45 years (SD = 11.96 years—1 participant did not indicate their age). The majority of participants were employed at universities (22), then in government/the public sector (12), the private sector (7), other (2) and not-for-profit (1). Participants self-reported their level of expertise (high, medium, low, none) and across the participant group, 20 (45.45%) participants had high level of expertise in road safety, 23 (52.27%) participants had high level of expertise in human factors and 14 (31.82%) participants had high level of expertise in systems thinking. The majority of participants (59.09%) reported a high to medium level of knowledge of the Aus-

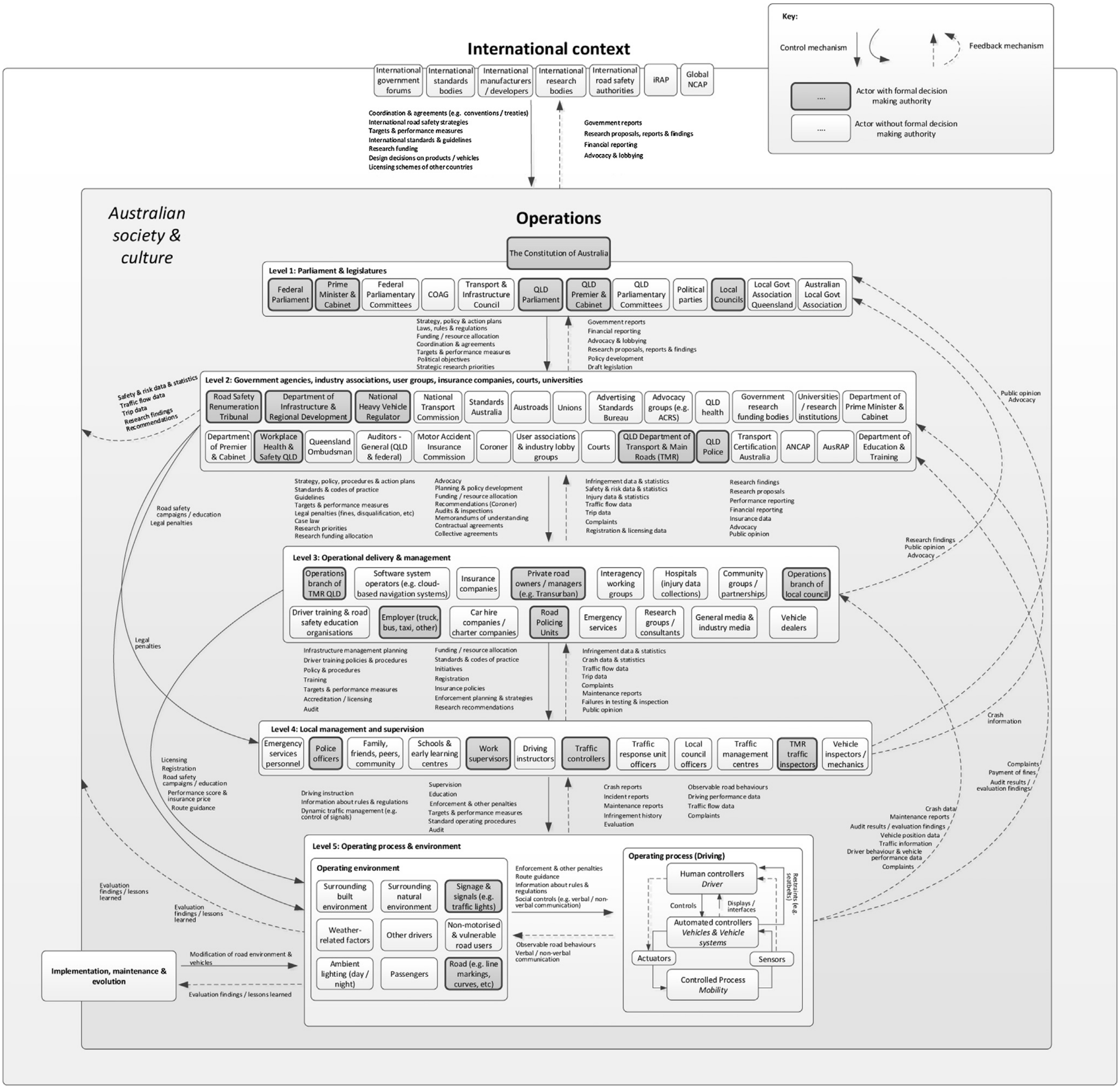

Fig. 2. Qld road transport system operations control structure.

tralian road transport system while 40.91% had a high to medium level knowledge of the Qld road transport system specifically.

Participants were provided with the final draft of the Qld control structure model along with a written overview of the STAMP method and the Qld control structure, and formal definitions for each control and feedback mechanism identified within the model. Additionally, they were provided with a link to an online questionnaire. Following a series of demographic questions designed to gather information on gender, age, experience, qualifications and expertise, the questionnaire requested participants to review the model and associated definitions and then respond to a set of questions regarding the control structure levels and actors, control mechanisms, and feedback loops (see Table 3).

An understanding of the level of consensus on the model was sought via the questions relating to the extent to which participants agreed that the model provided a comprehensive description of the actors, control mechanisms, and feedback loops embedded in the Qld road transport system. Consensus was said to exist when at least 80% of participants agreed that the overall model was appropriate and that no further modifications were required. Although this is more conservative than the level used in other Delphi studies (Keeney et al., 2006), this criterion was selected to represent as close to a unanimous view as possible.

Responses to the overall question of agreement with the model in Round 1 showed that 82.93% of participants agreed or strongly agreed that the draft model provides a comprehensive description of the Qld road transport system. However, a considerable amount of feedback was provided in response to the open-ended questions. On completion of Round 1, the analysts reviewed the feedback provided by participants, discussing each point and modifying the model where the feedback was deemed appropriate and within scope of the wider research program (for example, comments relating to issues outside of the fatal five behaviours, such as specific motorcycle and cyclist issues, were deemed out of scope). A revised

Table 1
Qld road transport system STAMP control structure levels.

Level	Description
Level 1: Parliament & legislatures	In the Australian system of government, there are both federal and state governments represented at this level. Their powers to legislate for different aspects of road transport are dictated by The Constitution of Australia, which is positioned at the top of this level to demonstrate its role in controlling the distribution of legislative powers amongst governments. Actors at this level include the state and federal parliaments, Ministers with transport portfolios, government committees and councils (including COAG – the Council of Australia Governments) and federal research funding bodies (such as the Australian Research Council and the National Health and Medical Research Council).
Level 2: Government agencies, user groups, industry associations, courts, universities	Government agencies as well as regulators, industry associations and user groups and the courts reside at this level. Such actors are generally enacted by legislation or hope to influence the legislatures. Actors at this level include government agencies and statutory bodies, safety regulators, user and industry associations and courts. A key government organisation at this level is the QLD Department of Transport and Main Roads (TMR).
Level 3: Operational delivery and management	The operational delivery and management level includes a range of organisations who are involved in road transport operations including the operational divisions of TMR (responsible for driver licensing, vehicle registration, etc.), as well as employers of professional drivers (such as heavy vehicle drivers, bus drivers, taxi drivers, etc.). It also includes groups such as ANCAP (who provides consumer safety ratings of new and used cars), hospitals (who collect and classify data about injuries following crashes), research groups and the media.
Level 4: Local management and supervision	This level includes the actors that can directly supervise and/or influence the driving process (e.g. the Police, parents, friends and peers). This level also includes actors such as the emergency services, schools, supervisors in the workplace, traffic controllers who direct drivers during roadworks, workers in the traffic management centre and vehicle mechanics/inspectors.
Level 5: Operating process and environment	The operating process for the road transport system is defined as the interaction of road users with vehicles and vehicle systems. This occurs through road users manipulating controls within the vehicle and gaining information about the vehicle's functioning via displays. Of course, in the road transport system there are many road users interacting with their vehicles, which are also included at this level. Also included is the road and related infrastructure which is part of the driving environment. This includes the road surface, road layout, road markings, signage, etc.

Table 2
Delphi study participants.

Gender and Age	Current Employment	Expertise (rated as high)	Knowledge of Australian and Qld Road Transport Systems
Round 1 respondents			
26 Male	University = 50%	Road Transport = 20%	*Australian road transport system*
18 Female	Government/public sector = 27%	Road Safety = 45%	High to Medium = 52%
Mean Age = 45yrs (SD = 11.96)	Private sector = 16%	Human Factors = 52%	*Qld road transport system*
	Not-for-profit = 5%	Systems Thinking = 32%	High to Medium = 41%
	Other = 2%		
Round 2 respondents			
15 Male	University = 56%	Road Transport = 11%	*Australian road transport system*
12 Female	Government/public sector = 22%	Road Safety = 33%	High to Medium = 57%
Mean Age = 46yrs (SD = 13.89)	Private sector = 15%	Human Factors = 41%	*Qld road transport system*
	Not-for-profit = 0%	Systems Thinking = 25%	High to Medium = 44%
	Other = 7.4%		

control structure model was developed through this process. In Round 2, the revised control structure model was disseminated to the original cohort of participants who were asked to respond again to the set of questions described in Table 1. Participants were also provided with general information on the changes made in line with feedback from Round 1, so that they could assess whether their views aligned with those of other participants, and change their opinions if desired.

3. Results

3.1. Delphi study results

Table 4 shows the Delphi study results relating to the extent to which participants agreed that the model provided a comprehensive description of the actors, control mechanisms, and feedback loops extant within the Qld road transport system.

As shown in Table 4, following Round 2 of the Delphi study, over 90% of participants indicated that they agreed that the model provided a comprehensive description of the actors, control mechanisms, and feedback loops associated with the Qld road transport system.

3.2. Qld road transport system control structure

The final Qld road transport system operations control structure model is presented in Fig. 2. Within Fig. 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. It is also worth noting that control mechanisms exist between non-adjacent levels (as represented by curved arrows). For example, at Level 3 the Department of Transport and Main Roads imposes licensing and registration controls on road users at Level 5.

The dashed arrows flowing upward through the model represent feedback mechanisms whereby actors and 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 turn 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

Table 3
Delphi questions.

Control structure levels and Actors
Are the level descriptors appropriate for this system? Are there any road transport-related actors missing that should be included in the control structure? If so, what are they and at what level should they be placed? Are there any actors in the draft control structure that are expressed incorrectly or should not be included? If so, what are they? Are there any actors in the draft control structure that would be better placed at another level within the diagram? If so, where should they be placed? Based on your knowledge of the Queensland road transport system or road transport systems generally, to what extent do you agree that the draft model comprehensively identifies all relevant levels and actors involved in the Queensland road transport system? (Strongly agree, agree, disagree, strongly disagree, don't know)
Control mechanisms
Are there any control mechanisms missing in the draft control structure? If so, what are they? Are there any control mechanisms in the control structure that are expressed incorrectly or should not be included? If so, what are they? Based on your knowledge of the Queensland road transport system or road transport systems generally, to what extent do you agree that the draft model comprehensively identifies all relevant control mechanisms operating within the Queensland road transport system? (Strongly agree, agree, disagree, strongly disagree, don't know)
Feedback mechanisms
Are there any feedback mechanisms missing in the draft control structure? If so, what are they? Are there any feedback mechanisms in the control structure that are expressed incorrectly or should not be included? Based on your knowledge of the Queensland road transport system or road transport systems generally, to what extent do you agree that the draft model comprehensively identifies all relevant feedback mechanisms operating within the Queensland road transport system? (Strongly agree, agree, disagree, strongly disagree, don't know)
Control/feedback within levels
Are there any important control mechanisms that exist between actors within levels of the control structure that you think should be identified in the model? Are there any important feedback mechanisms that exist between actors within levels of the control structure that you think should be identified in the model?
Overall
Overall, to what extent do you agree that the draft model provides a comprehensive description of the actors, control mechanisms and feedback mechanisms associated with the Queensland road transport system? (Strongly agree, agree, disagree, strongly disagree, don't know) Do you have any additional comments on the draft control structure or suggestions for improving the model?

Table 4
Delphi study results relating to participants' agreement with model contents.

	Model comprehensively identifies all actors	Model comprehensively identifies all relevant control mechanisms	Model comprehensively identifies all relevant feedback mechanisms	Model comprehensively identifies all relevant actors, control mechanisms and feedback mechanisms
Strongly agree	50% (13)	34.62% (9)	36% (9)	34.62% (9)
Agree	46.15% (12)	57.69% (15)	60% (15)	61.54% (16)
Total% agreement	96.15% (25)	92.31% (24)	96% (24)	96.16% (25)
Disagree	3.85% (1)	3.85% (1)	4%	3.85% (1)
Strongly disagree	0	0	0	0
Total% disagreement	3.85% (1)	3.85% (1)	4%	3.85% (1)
Don't know	0	3.85% (1)	0	0

arrows) or they may exist between non-adjacent levels (shown by curved dashed arrows).

A final feature of the model is the use of grey shading to denote those actors and organisations who have formal decision making authority. For example, at Level 1 the prime minister and cabinet node is shaded grey as they have formal decision making authority around controls such as a policy, strategies and actions plans, while the Federal and Qld Parliaments are shaded as they have the power to determine the passing of laws that regulate and otherwise influence the road transport system. Similarly, at Level 4, Police officers are shaded as they are able to enforce the road rules through mechanisms such as penalty notices.

3.3. Australian society and international influences

The two outer boxes surrounding the control structure model represent the Australian societal and international context within which the Qld road transport system operates. Australian society has an influence on road transport system behaviour at the various levels through social norms that influence people's choices (e.g. Meesmann et al., 2015) and the policies and strategies developed and adopted by organisations. The international context level includes the different organisations that enact influences or controls onto actors and organisations within the Qld road transport system. Road safety strategy and policy in Qld is impacted by decisions and commitments made in international government forums, such as the United Nations Road Safety Forum and the World Health Organisation (WHO) through their decade of road safety action plan (WHO, 2011). The vehicles designed and built by international vehicle manufacturers (e.g. General Motors, Hyundai, Ford), and the devices integrated within vehicles are required to confirm to standards set by international standards bodies, such as the International Organization for Standardization (ISO) who publish standards around vehicle design, intelligent transport system design etc. International road safety authorities and groups such as the international Road Assessment Program (iRAP) and Global New Car Assessment Program (Global NCAP) also influence many actors and organisations with Qld. For example iRAP provide assessment and ratings of roads and track road safety performance through AusRAP (see http://www.irap.org/en/about-irap/about-us).

In the context of the (control structure) model developed here, the controls enacted by the international level include international road safety strategies (e.g. the decade of action road safety plan), standards and guidelines (e.g. ISO standards), products such as vehicles, licensing schemes, and research funding. In turn, feedback coming out of the Qld road transport system includes government reports, research findings, financial reporting, and advocacy and lobbying.

3.4. Level 1 parliament and legislatures

Level 1 and its control and feedback relationships with Level 2 of the control structure are shown in Fig. 3. Level 1 of the control structure represents the highest level of the Qld road transport system, comprising both federal and state governments and related coordination agencies. With Australia being a federation, the law-making powers of the federal and state jurisdictions are delineated by the Constitution of Australia. For example, the Constitution states that the Federal Parliament can make laws relating to freedom of interstate trade and commerce. This allows for the making of national heavy vehicle regulations. However, there is no general power for federal legislation around road transport. Therefore, the states, including Qld, make their own road rules. Underneath the Constitution sit the state and federal parliaments, Ministers with transport portfolios, government committees and councils (including COAG – the Council of Australia Governments), political parties, local councils, the Australian Local Government Association and the Qld Local Government Association.

The primary control mechanisms enacted by this level are national policy, such as the National Road Safety Strategy 2011–2020 (NRSS; Department of Infrastructure and Regional Development, 2015) and laws and rules regarding operation of the road system. The NRSS includes a set of national road safety goals and actions and includes the target of reducing road deaths and serious injuries by 30% by 2020. Responsibility for implementing the NRSS is distributed across:

- the Federal Government, who is responsible for allocating resources for road networks and for regulating safety standards for road vehicles;
- state and territory governments, who are responsible for funding, planning, designing and operating the road network, for managing vehicle registration and driver licensing systems, and for overseeing the enforcement of road user behaviour;
- transport agencies (e.g. Transport and Main Roads Queensland, 2011), who are responsible for implementing actions laid out in the NRSS and its associated action plan.

Other control mechanisms enacted from this level downward include the provision of 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 (e.g. the Australian Government's Science and Research Priorities, see http://science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx).

The feedback mechanisms coming into Level 1 primarily relate to aggregated information regarding the overall safety and efficiency-related performance of the road transport system. This includes reports on the number of crashes and resulting fatalities and injuries, traffic flow and trip data, and information about the financial performance of government and government-funded agencies. Additional forms of feedback flowing into this level include road safety research findings that influence policy and road safety strategy, insurance data, advocacy and lobbying, and draft legislation.

3.5. Level 2: government agencies, industry associations, user groups, courts, universities

Levels 2 and 3 of the control structure are shown in Fig. 4. Level 2 of the control structure comprises federal and state government departments and statutory bodies (e.g. Department of Infrastructure and Regional Development), safety regulators (e.g. Workplace Health and Safety Qld), user groups and associations (e.g. Royal Automobile Club of Qld) the courts, state Coroners and regulators (e.g. the National Heavy Vehicle Regulator), the Motor Accident Insurance Commission (who regulate the compulsory third party insurance scheme in Qld) and the Qld Police.

There are various forms of control enacted by those at Level 2 on actors and organisations at Level 3, including standards (e.g. the Australian Design Rules), road transport policies, procedures and codes of conduct (e.g. transport infrastructure asset management policy), targets and performance measures, legal penalties (e.g. regulatory penalties issued on organisations), 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 feedback 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 Qld and Qld Police. Finally, insurance claims data is also fed up to the Motor Accident Insurance Commission by insurance companies.

3.6. Level 3: operational delivery and management

The operational delivery and management level of the model includes actors and organisations 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, since they investigate and report on matters relating to the delivery and management of road safety.

The actors and organisations included at this level are shown in Fig. 5 and include the operational division of Transport and Main Roads Qld who oversee all aspects of driver and vehicle licensing and registration. Organisations who employ professional drivers are also placed at this level, including freight organisations and public transport providers (e.g. bus and taxi services). Road safety research groups such as the Centre for Accident Research and Road Safety (CARRS-Q, see http://www.carrsq.qut.edu.au/) also reside at this level, as do hospitals as they collect injury information relating to road trauma. A notable group at this level is the Australasian New Car Assessment Program (ANCAP), an independent group who provides ratings on the safety features of different vehicle models available within Australia.

The actors and organisations at Level 3 enact many control mechanisms within the model. Some of the key control mechanisms enacted on those at Level 4 include infrastructure management planning, training (e.g. for professional drivers and driving instructors), policy and procedures around driver training

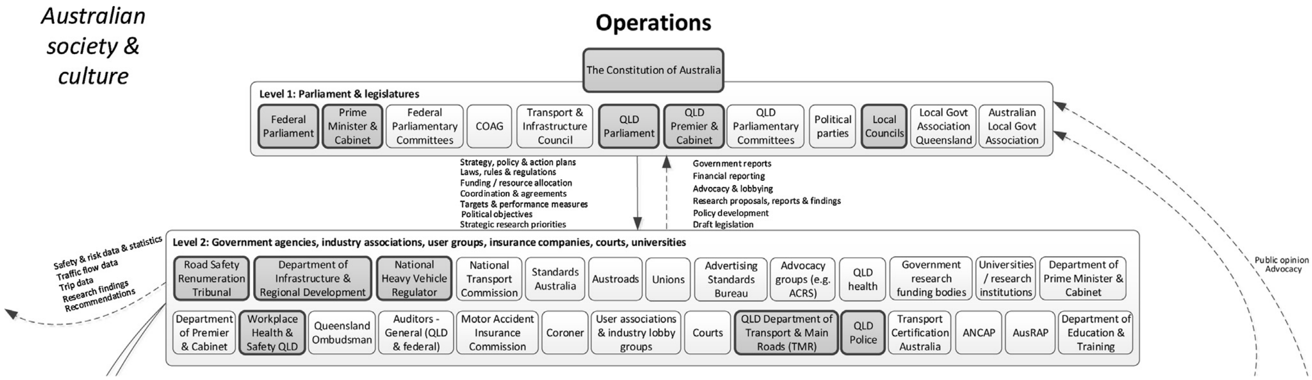

Fig. 3. Levels 1 and 2 of the Qld road transport system control structure.

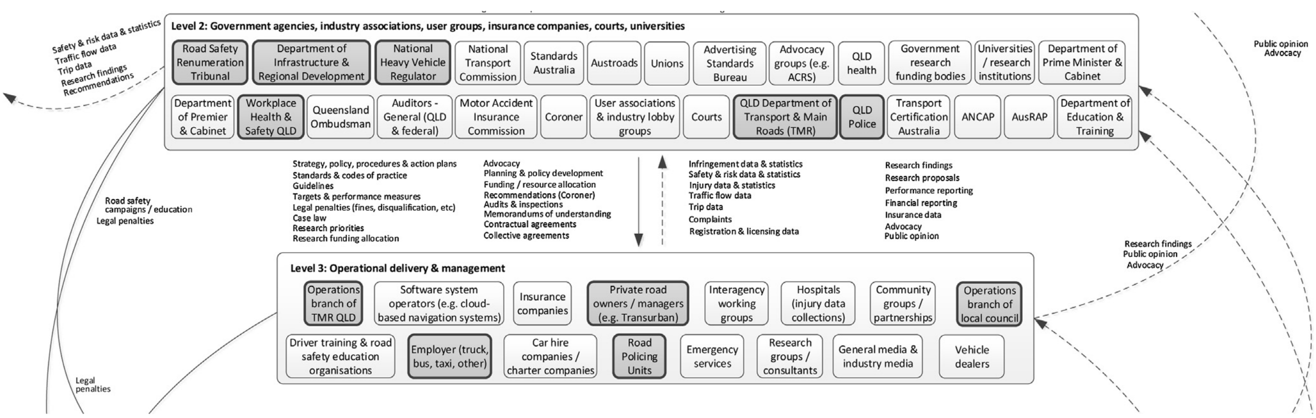

Fig. 4. Levels 2 and 3 of the Qld road transport system control structure.

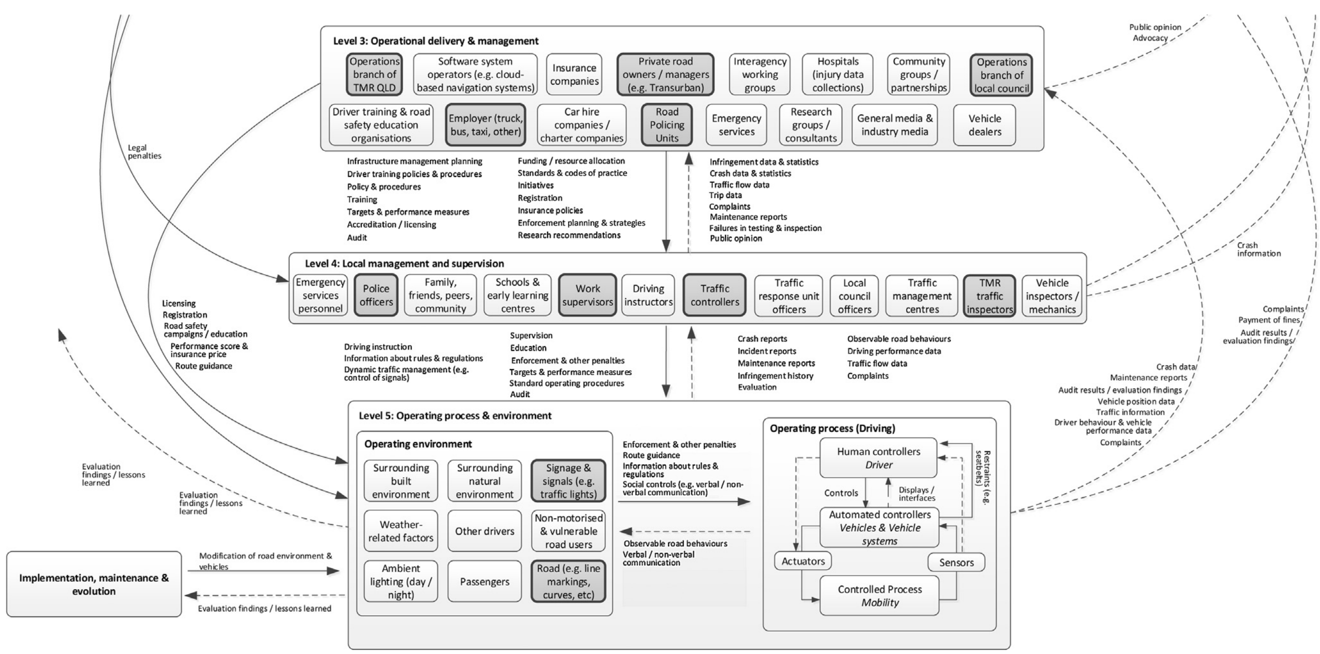

Fig. 5. Levels 3, 4 and 5 of the Qld road transport system.

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, community education programs etc.).

The actors and organisations situated at Level 4 in the model use a range of feedback mechanisms to update those operating at Level 3. The feedback mechanisms 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.

3.7. Level 4: local management and supervision

Level 4 in the control structure comprises actors and organisations that either directly control, supervise or influence behaviour on the roads. The primary actors at this level are Police officers who play a key role in supervising road user behaviour, enforcing road rules and regulations, and providing a traffic control function when necessary. The emergency services are also included as providing control mechanisms in the event of a road crash. Friends, parents and peers, and the community are also present at this level. For example, parents influence driver behaviour through various means including the strategies they use to teach their children to drive, how they educate their children, and how they regulate compliance with graduated licensing systems (Scott-Parker et al., 2015b). In addition, the influence of passengers and peers on driver behaviour is well known, particularly for young drivers (e.g. Taubman et al., 2015).

Additional supervisory controls are provided by parents and peers, schools, and workplace supervisors (for professional drivers and those who drive for work purposes). Other important actors at this level include driving instructors, traffic management centres and traffic response units. Traffic control mechanisms are facilitated by traffic management centres, which monitor traffic behaviour and work with the police, emergency services, road maintenance organisations and public transport providers to maintain network flow. Finally, vehicle inspectors and mechanics provide critical control functions related to road vehicles and the extent to which they are fit to be used on the road.

The control mechanisms enacted by those at Level 4 relate specifically to the control of road user behaviour. Police officers enforce the road rules through monitoring and measuring road user behaviour (e.g. speeds), alcohol and drug testing, examining the condition of vehicles, and issuing warnings and fines. Supervisory controls, such as monitoring driver behaviour, providing feedback on performance, and educational activities are enacted by parents, friends and family, workplace supervisors, and schools. Finally, mechanics and vehicle inspectors control the condition of road vehicles to ensure that they are within 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. This feedback is provided through crash reporting (e.g. driver statements to police and emergency services), incident reporting (e.g. drivers reporting to work supervisors regarding near miss incidents), 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.

3.8. Level 5: operating process and environment

The final level in the model incorporates vehicles and their human operators along with the operating environment which encapsulates the surrounding natural and built environment, weather and ambient conditions, the road infrastructure (e.g. road, road signage and signals) and other road users (e.g. drivers, passengers, non-motorised and vulnerable road users).

At this level the most basic form of control involves drivers exerting control over their vehicles (e.g. acceleration, steering) and, in turn, vehicle systems providing feedback about the status of the vehicle and vehicle performance back to the drivers (e.g. tachometer, speedometer). Outside of the vehicle, the operating environment enacts control on drivers through enforcement and penalties (e.g. speed cameras, red light cameras), route guidance through signage, information regarding rules and regulations (e.g. speed limit signage), the design of the road and built environment (e.g. roadways, barriers, footpaths), the natural environment (e.g. trees, hedges, grass verges) and social controls such as verbal and non-verbal communications from other road users. In addition, weather and the ambient lighting can also act as a form of control, restricting some drivers and influencing the behaviour of others. Feedback is provided to the operating environment by individual drivers and their vehicles via their observable on-road behaviours (e.g. compliance with speed limits and traffic signals) and communications with other road users (e.g. indicator use, physical gestures).

3.9. Control and feedback loops within levels and between non-adjacent levels

It is worth noting that control mechanisms were found to exist between non-adjacent levels (as represented by curved arrows in Figs. 2–4). For example, at Level 3 Transport and Main Roads Qld imposes licensing and registration controls on road users at Level 5. For feedback, road users at Level 5 of the model may make complaints about the road system (e.g. poor design or maintenance) to the Department of Transport and Main Roads Qld, advocacy groups, research groups etc. at Level 3 of the model. In addition, interactions (control, feedback, and other interactions) between organisations within each of the levels were identified; however, it was not possible to identify and represent them all in this study.

4. Discussion

The aim of this article was to present a STAMP control structure model of the Qld road transport system. The model was developed in response to recent calls for systems analysis methodologies to be used in road transport system modelling applications (e.g. Larsson et al., 2010; Salmon and Lenne, 2015). The control structure model depicts the range of actors and organisations operating within the Qld road transport system and outlines the key control and feedback relationships between them. The model represents an important first step in identifying the factors outside of road users, vehicles, and the road environment that play a role in the fatal five behaviours and road trauma. The following discussion focuses on some of the key implications of the model, namely who shares the responsibility for road safety, the nature and impact of the control and feedback mechanisms identified, and the extent to which current systems support the identification of crash contributory factors at the higher levels of the control structure model.

4.1. Who shares the responsibility for road safety?

For some time now road safety strategies worldwide have been driven by the accepted notion that road trauma in any given road transport system is a shared responsibility of all actors and organisations residing within that system. Despite this, discussion on who actually shares the responsibility for road trauma has been sparse, and has typically only referred to a sub-set of highly visible actors and organisations. For example, the NRSS argues that "Achieving lasting change in road safety will require governments, industry and the broader community to work together" (p. 32, Australian Transport Council, 2011), referring to a series of 'system managers' including road planners, designers, builders, vehicle engineers, fleet operators, policy makers, business professionals, and individual road users (Australian Transport Council, 2011). A key contribution of the control structure model is to go beyond this and provide some clarification around who actively shares the responsibility for road trauma in Qld. 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 presented. It can be concluded from the model that a diverse set of actors and organisations share the responsibility for road trauma in Qld. Notably, these go beyond the 'system managers' referred to above, covering the Constitution and government, government agencies, unions, research institutions, local government, road safety authorities, insurance groups, the media, driver trainers, advocacy groups, the police and emergency services, road users, parents and peers, and schools to name only a few. Another important finding from the model is the role that international organisations play in shaping the operation of Qld's road transport system.

4.2. What controls are enacted?

In her original article outlining the STAMP model, Leveson (2004) describes various forms of control, including managerial, organisational, physical, operational and manufacturing-based controls. It is interesting to note that all of forms of control outlined by Leveson (2004) are extant in the Qld road transport system. 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 attempts are made to actively control road users when they operate 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. Manufacturing-based controls are also evident; for example, in international standards for vehicle manufacturing.

In relation to the controls used to prevent the fatal five behaviours, the model shows how these are driven by road safety strategy and policy at the higher levels, are managed through organisations such as the Police and Transport Main Roads Qld, and are enacted on the roads either directly by Police, or indirectly by others such as parents, peers, and other road users. The primary form of control is enforcement of the road rules (e.g. random breath testing, speed cameras). An interesting finding is the high reliance placed on the Police in enacting controls (e.g. through enforcement). It may be worthwhile to identify other actors (human and non-human) who can enact controls also. Examples of these already in place include seatbelt warnings within vehicles and roadside speed cameras. With the ever-increasing use of advanced technologies, future research should explore how technologies and other actors can be exploited to enact both existing and newly developed road safety controls. Examples include in-vehicle fatigue detection systems, alcohol interlocks, and mobile phones that become unusable within road vehicles. Whilst new forms of control may be required, an important finding is that the enactment of controls should exploit actors other than the Police.

The relative strength of the controls is also interesting, particularly when compared to other more heavily regulated transport systems such as aviation and rail. Although similar forms of control are enacted in other transport systems, it is apparent that some forms of control are weaker within road transport. As a consequence there is more latitude for behaviour and, in turn, greater potential for controls to be less than optimal. For example, controls around driver impairment appear to be 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 (major airlines are required to perform random alcohol testing each year on at least 10% of their employees and drug testing on at least 25% of their employees, FAA, 2015). 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 less comprehensive and subsequently there is more latitude for road users to drive under the influence. The impact of this is seen through the prominent role of drink driving in road trauma. For example, in Qld between 2006 and 2011 over a quarter of all road crash fatalities involved a drink driver or rider. This is in contrast with civil aviation, where an Australian Transportation Safety Bureau (ATSB) database review of all crashes between 1975 and 2006 found a total of 22 crashes in which alcohol was a contributory factor. These accounted for only 0.02% of all occurrences recorded in the database for the same period (ATSB, 2006).

The same can said for the other key road trauma-related behaviours (fatigue, speeding, distraction, failure to use seat belts) whereby other transportation systems appear to 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 behaviours underpinning road trauma may be required. In the case of drink driving, for example, alcohol interlocks represent one obvious means of strengthening controls. However, whilst their effectiveness in preventing drink driving has been shown (Ullman, 2016); the practicalities around incorporating interlock devices into all vehicles are questionable. A systems approach such as that taken in the present study will enable the development of a suite of controls that target actors and organisations across the entire road transport system through identifying non-traditional avenues for intervention, particularly at the higher levels of the system. For example, given that many individuals will engage in work-related driving, subsidies provided by government or insurers to companies to improve fleet safety and driver training initiatives could have cross-over impacts on drivers' behaviours and expectations of employees when driving in a personal context.

4.3. Road trauma as a systems problem

An important finding from the analysis presented is further evidence that road trauma is a systems problem that is driven also by factors outside of road users, their vehicles, and the road environment. This is evidenced by the myriad actors and organisations within the control structure model that influence how the road transport system operates. In line with systems thinking it may be more appropriate to consider driver, vehicle and road environment factors as consequences rather than causes. That is they can be viewed as 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.

4.4. What controls fail?

The next step in a full STAMP analysis involves examining what controls fail in accident scenarios. In relation to road trauma-related incidents involving the fatal five behaviours, it is apparent that the known control failures reside at levels 4 and 5 of the control structure, including enforcement, education, social controls, vehicle control, and rules and regulations. Unfortunately, little is known about the role played by control failures at the other levels of the model. Indeed, a final important contribution of the model is that it raises questions regarding the extent to which existing road crash data collection and analysis systems consider contributory factors (or control and feedback failures) across the levels, actors and organisations described. By describing the road system in this manner, the model shows clearly that there are control and feedback relationships that can fail or be inadequate, which in turn influence road system behaviour. In doing so, the model suggests that interactions between these actors and organisations can play a role in creating or enabling the fatal five behaviours and road trauma—either through inappropriate or ineffective controls or a failure to implement controls. Other recent studies (e.g. Newnam and Goode, 2015; Salmon and Lenne, 2015) also suggest that there are important contributory factors that reside at the higher levels of road transport systems and 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. This raises important questions about current road crash data collection and analysis systems. In particular, whether they are sufficiently identifying the range of contributory factors involved in road trauma. Even with the most in-depth crash systems, the identified contributory factors are heavily oriented around drivers, their vehicles, and the road environment, with little information regarding less direct contributory factors residing at the higher levels of the system (Salmon et al., 2010). In relation to the control structure model presented, this suggests that currently only the crash contributory factors residing at the operating process and environment level (e.g. driver, vehicle, and environmental factors) are well understood. Aside from selected additional factors at the local management and supervision level (e.g. the role of passengers), there is little understanding of, and no data available on, a range of potential crash contributory factors across the five other levels specified in the control structure model. Examples might include issues related to driver training programs, work pressures, traffic management, licensing and registration, road rules and policy, road design and manufacturing processes, funding etc; however, without the appropriate data collection and analysis systems it is not possible to identify these factors. A key contribution of the model presented is to further emphasise this capability gap.

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 is one that is further emphasised through this study. Notably, similar systems have been developed in other areas and have resulted in advances in the knowledge base around the contributory factors involved in accidents (See Salmon et al., in press). As a key first step in the process of improving road crash data systems, the authors are currently mapping Qld's road crash data onto the control structure in order to highlight where gaps in the knowledge base exist. Following this, SME workshops will be held to identify potential contributory factors at the higher levels of the control structure.

4.5. How suitable is STAMP for road safety applications?

As a first of its kind application in road safety the analysis revealed that while STAMP's control structure could be usefully applied to understand Qld's road transport system, some important methodological limitations were identified. One feature of the control structure model is that many of the mechanisms identified may not in-fact represent controls per se, rather they may be more accurately described as influencing mechanisms (for example, education, supervision, initiatives). Whilst this shows the importance of mechanisms for influencing behaviour in road transport systems, it also points to a lack of formal controls, both at the lower (e.g. road user) and higher levels of the system. In relation to the STAMP method it potentially provides an important extension, whereby differentiation is made between controls and influencing factors; it could be useful for example to develop an influencing structure as well as a control structure. A second limitation relates to its inability to represent some of the wider societal influences on road user and road system behaviour. Such influences represent key drivers underpinning driving behaviours (May et al., 2008; Johnston, 2010); however, the explicit focus on control and feedback mechanisms ensures that it is difficult to incorporate such influences in the model. This may provide one avenue for methodological development that will enhance the utility of STAMP in the road transport context. A third and final limitation is that, in the present study at least, the control structure only describes control and feedback interactions between levels (inter-level interactions), whereas there are likely many important interactions occurring within levels (intra-level interactions). Indeed, some of these were raised by the Delphi study participants. It is recommended that future studies examine this, and also that future applications of STAMP in other areas seek to comprehensively identify relationships both between and within different levels of the control structure.

5. Conclusion

It is concluded that there are a diverse set of actors and organisations involved in controlling road safety in Qld, Australia. Whilst many controls are enacted, other mechanisms appear to offer influence rather than direct control, and the strength of some controls is questionable, especially when compared to other safety critical domains. Further research should explore the role of higher road system levels in crash causation along with the potential for new forms of control around the fatal five behaviours that drive road trauma.

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 in the road safety context are encouraged, particularly around crash causation, the composition of road systems, and the influence of higher level actors and organisations on the behaviour of important actors such as road users and road designers. It is these authors opinion that the rich outputs from such applications will support the optimisation of road transport systems and attainment of further road safety gains.

References

Australian Transport Safety Bureau, 2006. Accidents and incidents involving alcohol and drugs in Australian civil aviation: 1st January 1975 to 31st March 2006. ATSB Transport Safety Report. Aviation Safety Research and Analysis Report B2006/0169. https://www.atsb.gov.au/media/32870/b20060169_001.pdf (accessed 14.12.15.).

Australian Transport Council, 2011. The National Road Safety Strategy 2011–2020. http://www.atcouncil.gov.au/documents/files/NRSS_2011_2020_15Aug11.pdf (accessed 21.11.11.).

Cornelissen, M., Salmon, P.M., McClure, R., Stanton, N.A., 2013. Using cognitive work analysis and the strategies analysis diagram to understand variability in road user behaviour at intersections. Ergonomics 56 (5), 764–780.

Cornelissen, M., Salmon, P.M., McClure, R., Stanton, N.A., 2015. Assessing the 'system' in safe systems-based road designs: using cognitive work analysis to evaluate intersection designs. Accid. Anal. Prev. 74, 324–338.

Dekker, S., 2011. Drift into Failure: from Hunting Broken Components to Understanding Complex Systems. Ashgate, Aldershot, UK.

Department of Infrastructure and Regional Development, 2015. National Road Safety Strategy 2011–2020: Implementation status report. https://infrastructure.gov.au/roads/safety/national_road_safety_strategy/ (accessed 16.11.15.).

Dommes, A., Granié, M.A., Cloutier, C., Coquelet, F., Huguenin-Richard, 2015. Red light violations by adult pedestrians and other safety-related behaviors at signalized crosswalks. Accid. Anal. Prev. 80, 67–75.

Federal Aviation Administration, 2015. Guidance alert: FAA Random Drug and Alcohol Testing Program. https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/drug_alcohol/policy/faa/media/guidance-alert-on-random-testing.pdf (accessed 14.12.15.).

Goh, Y.M., Love, P.E.D., 2012. Methodological application of system dynamics for evaluating traffic safety policy. Saf. Sci. 50 (7), 1594–1605.

Goode, N., Salmon, P.M., Lenne, M.G., Hillard, P., 2014. Systems thinking applied to freight handling operations. Accid. Anal. Prev. 68 (July), 181–191.

Johansson, R., 2009. Vision zero—implementing a policy for traffic safety. Saf. Sci. 47, 826–831.

Johnston, I., 2010. Beyond best practice road safety thinking and systems management—a case for culture change research. Safety science 48, 1175–1181.

Keeney, S., Hasson, F., McKenna, H., 2006. Consulting the oracle: ten lessons from using the Delphi technique in nursing research. J. Adv. Nurs. 53, 205–212.

Kim, T.E., Nazir, S., Øvergård, K.I., 2016. A STAMP-based causal analysis of the Korean Sewol ferry accident. Saf. Sci. 83, 93–101.

Knight, P.J., Iverson, D., Harris, M.F., 2013. The perceptions of young rural drivers in NSW, Australia of speeding and associated risk: a mixed methods study. Accid. Anal. Prev. 55, 172–177.

Larsson, P., Dekker, S.W.A., Tingvall, C., 2010. The need for a systems theory approach to road safety. Saf. Sci. 48 (9), 1167–1174.

Leveson, N.G., 2004. A new accident model for engineering safer systems. Saf. Sci. 42 (4), 237–270.

Linstone, A.H., Turoff, M., 1975. The Delphi Methods: Techniques and Applications. Addison–Wesley, Reading, Massachussetts.

May, M., Tranter, P.J., Warn, J.R., 2008. Towards a holistic framework for road safety in Australia. J. Transp. Geogr. 16 (6), 395–405.

McClure, R.J., Adriazola-Steil, C., Mulvihill, C., Fitzharris, M., Bonnington, P., Salmon, P.M., Stevenson, M., 2015. Simulating the dynamic effect of land use and transport policies on the development and health of populations. Am. J. Public Health 105 (S2), 223–229.

Meesmann, U., Martensen, H., Dupont, E., 2015. Impact of alcohol checks and social norm on driving under the influence of alcohol (DUI). Accid. Anal. Prev. 80, 251–261.

Newnam, S., Goode, N., 2015. Do not blame the driver: a systems analysis of the causes of road freight crashes. Accid. Anal. Prev. 76, 141–151.

Pasmore, W., Francis, C., Haldeman, J., Shani, A., 1982. Sociotechnical systems: a north American reflection on empirical studies of the seventies. Hum. Relations 35 (12), 1179–1204.

Rasmussen, J., 1997. Risk management in a dynamic society: a modelling problem. Saf. Sci. 27 (2/3), 183–213.

Read, G., Salmon, P.M., Lenne, M.G., 2013. Sounding the warning bells: the need for a systems approach to rail level crossing safety. Appl. Ergon. 44, 764–774.

Reason, J., 1997. Managing the Risks of Organisational Accidents. Ashgate Publishing Ltd., Burlington, VT.

Salmon, P.M., Lenne, M.G., 2015. Miles away or just around the corner: systems thinking in road safety research and practice. Accid. Anal. Prev. 74, 243–249.

Salmon, P.M., McClure, R., Stanton, N.A., 2012. Road transport in drift? Applying contemporary systems thinking to road safety. Saf. Sci. 50 (9), 1829–1838.

Salmon, P.M., Read, G., Stanton, N.A., Lenné, M.G., 2013. The Crash at Kerang: investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. Accid. Anal. Prev. 50, 1278–1288.

Salmon, P.M., Goode, N., Taylor, N., Dallat, C., Finch, C., Lenne, M.G., in press. Rasmussen's legacy in the great outdoors: a new incident reporting and learning system for led outdoor activities. Appl. Ergon. (accepted for publication 14th July 2015).

Salmon, P.M., Lenne, M.G., Mulvihill, C., Young, K., Cornelissen, M., Walker, G.H., Stanton, N.A., 2016. More than meets the eye: using cognitive work analysis to identify design requirements for safer rail level crossing systems. Appl. Ergon. Part B 53, 312–322.

Scott-Parker, B., Goode, N., Salmon, P.M., 2015a. The driver, the road, the rules. . .. . ..and the rest? A systems approach to young driver safety. Accid. Anal. Prev. 74, 297–305.

Scott-Parker, B., Watson, B., King, M.J., Hyde, M.K., 2015b. I would have lost the respect of my friends and family if they knew I had bent the road rules: parents, peers, and the perilous behaviour of young drivers. Transp. Res. Part F: Traffic Psychol. Behav. 28, 1–13.

Stephens, A.N., Fitzharris, M., 2016. Validation of the Driver Behaviour Questionnaire in a representative sample of drivers in Australia. Accid. Anal. Prev. 86, 186–198.

Taubman, O.B.S., Kaplan, S., Lotan, T., Giacomo Prato, C., 2015. Parents' and peers' contribution to risky driving of male teen drivers. Accid. Anal. Prev. 78, 81–86.

Transport and Main Roads Queensland, 2011. Fatal road traffic crashes in Queensland: A report on the road toll. https://www.qld.gov.au/transport/safety/road-safety/statistics/index.html (accessed 14.12.15.).

Ullman, D.F., 2016. Locked and not loaded: first time offenders and state ignition interlock programs. Int. Rev. Law Econ. 45, 1–13.

Underwood, P., Waterson, P., 2014. Systems thinking, the Swiss Cheese Model and accident analysis: a comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models. Accid. Anal. Prev. 68, 75–94.

World Health Organisation, 2011. Global Plan for the Decade of Action for Road Safety 2011–2020. http://www.who.int/roadsafety/decade_of_action/plan/en/index.html (accessed 21.11.11.).

World Health Organisation, 2014. The top ten causes of death. http://www.who.int/mediacentre/factsheets/fs310/en/ (accessed 12.07.14.).

Wegman, F., Aarts, L., Bax, C., 2008. Advancing sustainable safety National road safety outlook for the Netherlands 2005–2020. Saf. Sci. 46, 323–343.

Zhang, Y., Shao, W., Zhang, M., Li, H., Yin, S., Xu, Y., 2016. Analysis 320 coal mine accidents using structural equation modeling with unsafe conditions of the rules and regulations as exogenous variables. Accid. Anal. Prev. 92, 189–201.