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Editorial

Miles away or just around the corner? Systems thinking in road safety research and practice

1. Introduction

The facts around current and projected levels of road trauma need little introduction: in 2012 road injury was the ninth leading cause of worldwide deaths (WHO, 2014) and it is estimated that by 2030 it will be the fifth (WHO, 2009). Its presence in the World Health Organisation's top ten causes of death gives a clear indication of the scale of the problem: currently road injury stands alone within this list as the only non-disease-related issue. The inescapable truth is that road transport systems kill people on a scale that is comparable to cancers, cardiovascular disease, and respiratory diseases.

There is no doubt that significant progress has been made by the road safety community in our attempts to reduce road trauma. There are numerous success stories and countless lives have been saved through many forms of intervention. It is indisputable that in most areas roads are now the safest they have ever been. Recent paradigm shifts in the approach to road safety, such as the Swedish Vision Zero and Dutch Sustainable Safety approaches (see Johansson, 2009; Wegman et al., 2008), have had a significant impact. Despite this, we are still faced with unacceptable levels of road trauma that result from problems that have so far proved resistant to interventions, or where the impact of successful interventions is beginning to plateau. As evidenced by the figures mentioned above, our road systems still kill and injure people on a regular basis. Worse still, in some lower and middle-income countries the road toll is increasing. At best, this suggests that past approaches to reducing road trauma may have reached their limit in terms of their effectiveness. At worst, it suggests that the global response to road trauma is now failing.

As road safety practitioners and researchers we appear to be faced with a stark choice in terms of how we continue to pursue improvements in road safety. Do we continue with previously successful approaches and accept that only small, incremental improvements may be achieved? Or is a new paradigm shift needed to facilitate greater road safety gains? The impetus for this special issue was derived from these authors' belief that the latter option is now the most viable (Salmon and Lenné, 2009; Salmon et al., 2012). It is our contention (and others' e.g. Johnston et al., 2014; Larsson et al., 2010; Read et al., 2013) that a new approach is needed if further significant reductions in road trauma are to be realised. Such an approach is needed to deal with the longstanding issues that continue to resist current interventions, such as collisions at intersections, collisions between different forms of road user (e.g. drivers and motorcyclists), young drivers, rail level crossings, distraction, and impairment (e.g. fatigue and drink and drug driving).

What might a new approach to road safety entail? Based on successful applications in other safety-critical domains, there is growing consensus that increased reductions in road trauma may be facilitated by applying so-called systems thinking-based approaches (Larsson et al., 2010; Salmon et al., 2012; Read et al., 2013). These include models of system safety (e.g. Rasmussen, 1997), systems thinking design principles such as those derived from Sociotechnical Systems Theory (e.g. Clegg, 2000; Davis et al., 2014) and systems analysis and design methodologies (e.g. Checkland, 2000; Hollnagel, 2012; Leveson, 2004; Stanton et al., 2013; Sterman, 2000; Svedung and Rasmussen, 2002; Vicente, 1999).

Encouragingly, there is a groundswell of research that is beginning to apply systems thinking models and methods to road safety issues. The aim of this special issue is twofold: first, to provide a platform for communicating this research and showcasing the different approaches involved, and second, to inspire the road safety community to further integrate systems thinking in road safety research and practice. In this editorial we first discuss the key tenets of systems thinking before providing an overview of each article presented in the special issue. In closing, we articulate the key take home messages, providing a research agenda to facilitate further systems thinking applications in road safety.

2. Key tenets of systems thinking

The term "systems thinking" in this case is used to describe a philosophy currently prevalent within the discipline of human factors that is applied to understand and improve performance and safety in complex sociotechnical systems. It is most prominent in the area of accident analysis where, since first emerging in part in the early 1900s (e.g. Heinrich, 1931), it is now characterised by a series of accident causation models and analysis methods (e.g. Leveson, 2004; Perrow, 1984; Rasmussen, 1997; Reason, 1997; Svedung and Rasmussen, 2002). Contemporary models are underpinned by the notion that safety, and indeed accidents, are emergent properties arising from non-linear interactions between multiple components across complex sociotechnical systems (e.g. Leveson, 2004). For example, Rasmussen's risk management framework (Rasmussen,

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1997) is one currently popular systems thinking model that is beginning to be applied in road safety settings (e.g. Salmon et al., 2013); this argues that systems comprise various levels (e.g. government, regulators, company, company management, staff, and work), each of which are co-responsible for production and safety. Decisions and actions at all levels of the system interact with one another to shape its performance: both safety and accidents are thus shaped by the decisions of all actors, not just the front line workers in isolation, and accidents are caused by multiple contributing factors, not just one bad decision or action. A key implication is that it is not possible to truly understand safety and performance through decomposing the system into component parts and examining these parts alone (e.g. drivers, vehicles); rather, it is the interactions between the components that are of interest. Further, the more components and interactions studied together, the closer one can get to understand performance and the factors influencing it. Notably, it has been pointed out the prevalent approach in road safety has been component oriented, focussing mainly on components such as individual road user groups and attempting to improve their behaviour (Cornelissen et al., 2013; Larsson et al., 2010; Read et al., 2013; Salmon et al., 2012; 2014). Whilst this is no doubt important, systems thinking argues that the road user is just one part of a rich interlinked web of human and technical components and needs to be studied in the context of the interactions with these other components.

Rasmussen's framework makes a series of assertions regarding accident causation that provide a suitable systems thinking framework for studying road safety issues. These have been adapted below to fit the road safety context:

1. Road safety and road crashes are emergent properties impacted by the decisions and actions of all actors, not just road users alone;
2. Threats to road safety are caused by multiple contributing factors, not just a single poor decision or action;
3. Threats to road safety can result from a lack of poor communication and feedback (or 'vertical integration') across levels of the system, not just from deficiencies at one level alone;
4. Lack of vertical integration is caused, in part, by lack of feedback across levels of the road transport system;
5. Road system behaviours are not static, they migrate over time and under the influence of various pressures such as financial and psychological pressures;
6. Migration occurs at multiple levels of the road transport system;
7. Migration of practices cause system defences to degrade and erode gradually over time, not all at once. Road crashes are caused by a combination of this migration and a triggering event(s).

These predictions have a number of key implications for road safety research and practice. It is precisely these implications that, in our view, should drive a paradigm shift in how we attempt to understand and enhance safety and performance in road transport systems. In this sense they form the foundations for the research agenda required to drive systems thinking in road safety research and practice. First, research and practice should focus on the decisions and actions made by all actors within road transport systems, not just road users alone; according to the framework even when it is clear that factors such as distraction, speeding, or impairment were involved in a road traffic crash, there are still behaviours and interactions of interest that enabled the adverse road user behaviour and resulting crash. It has previously been pointed out, however, that current road traffic crash data systems do not consider factors outside of road users, vehicles, and the road environment (e.g. Salmon et al., 2012). There are practical and logistical reasons that currently prevent such data being collected, but nonetheless, systems thinking necessitates that systems be developed to collect more expansive data. Research from other safety domains tells us that clarifying the role of other factors in road traffic crashes is a necessity if interventions are to be successful. Second, interventions can focus on improving behaviour and decision-making across all levels of road transport systems, not just in road users alone. Historically road safety research has focussed on road user behaviour and how to improve it, and more recently strategies have incorporated a focus on developing safer vehicles and road environments. Whilst interventions have proven successful in improving road user behaviour and compliance and the safety of vehicles and road environments, Rasmussen's framework suggests that the decisions and actions of others within the system should also be focussed on; more importantly, the decisions and actions of those at the higher levels of the road transport system potentially have more of an influence on overall levels of trauma. These other actors include policy makers, road and vehicle designers, road safety authorities, and government to name only a few. Third, the extent to which vertical integration is present in road transport systems requires investigation. Interactions across different levels of road transport systems have received little attention to date, yet they could conceivably shed light on road trauma. Research and practice should aim to understand and enhance communication and feedback across road transport systems. Fourth, the pressures and constraints that influence road transport system behaviour as a whole, and behaviour at different levels of road transport systems, need to be identified. Whilst financial and psychological pressures certainly play a role, less is known about other pressures such as political and organisational constraints. Without clarifying what these factors are and what their impact is, it is impossible to prevent migration of behaviour and safety towards that which is unacceptable.

2.1. A note on the difference between systems thinking and contemporary road safety strategies

As evidenced by a range of submissions to this special issue that were in fact not consistent with the theme of systems thinking there is often confusion in road safety circles that a systems thinking approach is currently being adopted through contemporary road safety strategies such as Vision Zero (Johansson, 2009), the Dutch sustainable safety strategy (Wegman et al., 2008), the Australian Safe Systems approach (ATC, 2011), and the UN Decade of Action for Road Safety (WHO, 2011). Whilst these strategies do contain elements of systems thinking and its language, they are not underpinned by systems thinking nor do they adopt systems thinking models and methods during implementation activities. Before providing an overview of the contributions to this special issue it is first worth clarifying some of the key differences between systems thinking as referred to here and contemporary road safety strategies.

There is no doubt that some of the key principles of systems thinking are present within contemporary road safety strategies. For example, acknowledging human fallibility and the idea that safety is the responsibility of all actors within the road transport system are both key tenets of current road safety strategies and likewise are key tenets of systems thinking models such as Rasmussen's (1997). Strategies such as the Australian safe systems road safety strategy also target different forms of road user along with factors outside of road users that play a role in road trauma, such as roadway design and vehicles (ATC, 2011). Moreover there is acknowledgement that there are other economic, social and technological factors that play a role in road trauma. Despite these similarities, some of the philosophies underpinning systems thinking are in contradiction to those underpinning road safety strategies. For example, within road safety strategies there

remains a focus on describing behavioural failures as 'error', a concept which is no longer thought to be meaningful or useful by most systems thinkers (Hollnagel, 2009; Dekker, 2011). The concept of error tolerance and designing forgiven systems is also given more emphasis in current road safety strategies; whilst human fallibility is a key philosophy of systems thinking, most systems thinking approaches place more emphasis on designing systems to support adaptive behaviour and resilience.

A further point of difference lies in systems thinking's arguments surrounding the overall system itself being the most appropriate unit of analysis, and the notion that interactions, rather than components, are of interest when attempting to understand and enhance behaviour. Whilst systems thinking is underpinned by both principles, contemporary road safety strategies are not, and while emphasising various pillars (safe road users, roads, vehicles etc.), ultimately end up focussing on the behaviour of road users and how it can be improved. Many strategies, for example, focus on improving the behaviour of young drivers, older drivers, and motorcyclists. Moreover, interventions are typically focussed on the road users themselves (e.g. training, education, enforcement). These areas of focus are appropriate and have led to reductions in known risks to the different road user groups; we argue however that a systems thinking approach to real-world problems is likely to deliver new more widespread and longer-lasting safety benefits. A focus on road users alone likely leaves many other pertinent factors free to continue influencing behaviour. In this sense road user behaviour can act as a red herring – other factors are creating the behaviours that lead to crashes. The extent to which current strategies do adopt systems thinking approaches is discussed further in papers contained with this special issue.

2.2. Special issue contributions

The aims of this special issue are to showcase emerging applications of systems thinking models and methodologies in road safety and to inspire new applications based on the research agenda presented. The issue contains papers that address the applicability and current application of systems thinking models in road safety and applications of systems thinking to specific issues such as young drivers and vulnerable road user groups, distraction, and road design. In addition, selected papers describe 'safe systems applications' in which steps are taken to integrate systems thinking. A summary of each contribution and its key findings is presented below.

2.3. Systems thinking models

As noted above, there are many models underpinned by philosophies related to systems thinking. Furthermore, there are many more that either use elements of systems thinking language or are use the term 'systems' in their rhetoric. These models span disciplines and domains and have been applied to many problems. In the perfect opening contribution to this special issue, Hughes et al. (2014, a review of models relevant to road safety) present a review and critique of 'system safety' models which aimed to examine the extent to which the systems models presented in the literature have been applied in, and could be applied in, road safety. Based on a review of the literature they identified 121 models that are subsequently categorised into seven types: component, sequence, intervention, mathematical, process, safety management, and systems models. Hughes et al. (2014a) compare and critique the models based on their applications, main strengths and weaknesses, and relevance to road safety. The review reveals that, although many of the models identified could be applicable to road safety, few of them have been applied in this context. In particular, Hughes et al. (2014a) note how applicable models related to systems theory, safety management systems, risk management, and safety culture have not commonly been applied in road safety. Further, the review also revealed that other safety critical domains have typically taken a wider perspective than road safety has, recognising the role of multiple wider systemic factors in safety and accident causation. Hughes et al. (2014a) argue that the ability of systems thinking models to be expansive in their focus gives them a significant advantage over the other models examined. In conclusion, they argue that models applied in other safety critical domains should be considered for future road safety applications.

In a companion paper, Hughes, Anund & Falkmer (System Theory and Safety Models in Swedish, UK, Dutch and Australian Road Safety Strategies) analyse the evolution of Vision Zero, Sustainable Safety and the safe system style road safety strategies. The successful Swedish, United Kingdom and Dutch road safety strategies are compared to both the older and newer Australian road safety strategies. Further, the content of these four modern cases of road safety strategy was compared against each other, and reviewed against both scientific systems theory and different types of safety model. The strategies contained substantial similarities, but were different in terms of fundamental constructs and principles. While acknowledging strong and unique features of each strategy, Hughes et al. (2014b) suggest that the modern strategies do not include essential aspects of systems theory that describe relationships and interdependencies between key components. Hughes et al. (2014b) conclude that the description of these strategies as systems is therefore not well founded and deserves further development, initially at a conceptual level.

2.4. Vulnerable road users

Vulnerable road users such as pedestrians, cyclists and motorcyclists often form a key component of road safety strategies. Acknowledging the limitations extant in current road traffic crash data, Regan et al. (2014) (Use of Cognitive Work Analysis to Derive Recommendations for Improving Powered Two Wheeler Safety) present a novel application of the Work Domain Analysis (WDA) method from the Cognitive Work Analysis framework (CWA; Vicente, 1999) to examine how Powered-Two Wheel (PTW) vehicle riders manage their own and other road users' safety. As part of the European Commission's 2-be-Safe (FP7) project, based on interviews with twenty-seven experienced riders from Paris, Vienna and Melbourne, Regan et al. (2014) present an abstraction decomposition space that describes the PTW domain across five levels of abstraction, ranging from its overall purpose to its component physical objects. Following this, they use work organisation analysis to identify the key tasks undertaken within the PTW domain along with their relationships to the functions identified in the abstraction decomposition space. Regan et al. (2014) use these new representations of PTW riding to explore the constraints imposed on PTW behaviour, potential negative consequences brought about by the introduction of interventions designed to improve safety (e.g. road markings that become slippery when wet), and new strategies and interventions for improving safety. In conclusion they emphasise the need for road safety research to focus on road users management of their own safety and that of other road users, suggesting that this will create new knowledge that could inform the development of novel and perhaps more effective road safety interventions. A final but important conclusion made by Regan et al. (2014) lies in their perceived value of the CWA-based approach adopted: in particular they note that some of the questions raised by the analysis would not typically be raised through traditional epidemiological road safety approaches.

Bambach and Mitchell (safe systems approach to reducing serious injury risk in motorcyclist collisions with fixed hazards) conducted a safe system analysis of the effectiveness of treatments

to minimise the risks posed to motorcycles by fixed hazards in the roadway environment. While previous studies have shown that the individual treatments, including roadside barriers and behavioural initiatives around helmet and alcohol use, have been effective in reducing injury to motorcyclists, the aim of this study was to quantitatively analyse these combined effects and thereby to compare the holistic safe system approach with the approach of considering each effect individually. Crash data from both Australia and the United States were examined, and while not able to include data on safe vehicles, data associated with each of the other safe system cornerstones were considered: the presence of a roadside barrier in front of the hazard (safe roadways); the motorcyclist was wearing a helmet (safe vehicles and protective devices); the crash was speed-related (safe speeds); and the crash was alcohol-related (safe people). The results indicate that the presence of a roadside barrier, wearing of a helmet, not riding with excessive speed and not riding under the influence of alcohol each typically provided modest safety benefits to motorcyclists in fixed object collisions individually. However, the greatest safety benefits were achieved when all measures occurred concomitantly. These findings are presented as support for a holistic safe system approach.

2.5. Young road users

In most jurisdictions young drivers continue to be over represented in road crash statistics. For example, the Australian Bureau of Infrastructure, Transport, and Regional Economics (BITRE, 2013) reports that, worldwide, the population based rate for road deaths in young adults is over 50% higher than for all age groups. Moreover, they estimate that, in developed countries, road traffic crashes account for around a quarter of all 15 to 24 year old deaths (BITRE, 2013). Scott-Parker, Goode and Salmon (The driver, the road, the rules and the rest?) argue that the prevalent approach to understanding and enhancing young driver safety has been driver-centric and that a systems approach is required to better understand the problem and to produce more holistic interventions. Scott-Parker and colleagues applied Rasmussen's risk management framework to investigate what is currently known about the young driver crash problem, to identify who shares the responsibility for it, and to determine what parts of the road system countermeasures have typically focussed on. Scott-Parker et al's (2014) ActorMap analysis demonstrates that there are multiple stakeholders across the Queensland road transport system that currently plays a role in young driver safety. From their assessment of what is currently known on the causes of young driver crashes, they conclude that the majority of the literature is focused on contributory factors related to the drivers themselves or their vehicles. They argue that it is likely that there are other contributory factors across road systems that require further investigation. Finally, their analysis of young driver crash countermeasures shows that these have focussed on either enhancing young driver skill sets through education or training or on modifying their behaviour through technology, infrastructure, or graduating licensing systems. Again, they argue that there are likely other parts of road systems that could be focussed on during countermeasure development, such as parents and peers. Scott-Parker conclude that the current 'fix the young driver' approach is limited, and that a systems approach that considers the overall road system and the interactions between those who play a role in young driver safety is required. In closing they propose a research agenda to facilitate adoption of a systems approach in young driver research and practice.

Twisk et al. (2014) (quantifying the influence of safe road systems and legal licensing age on road mortality among young adolescents) investigate the relatively high road morality rate of young adolescents. They propose a conceptual health behaviour logic model of adolescent risky behaviour and its systemic influences that depict the interrelationships amongst these individual and systemic influences. The model argues that threats to adolescent safety emerge from processes and interactions at both the individual and systemic level. The relationships specified are tested through the use of data on road fatalities in Canada, Australia, and New Zealand, between 2001 and 2008 to investigate the influence of two factors on safety: system-induced exposure to risk (transport mode choice and safety of the road system as a whole) and the licensing age. The analysis reveals that road systems with low system-induced exposure levels protect adolescents better than systems with higher levels; however, the influence of driver licensing age on adolescent safety was not significant. Twisk et al. (2014) conclude that road systems can protect adolescents better not by attempting to eliminate their tendency to take risks or partake in new behaviours, but by eliminating hazardous conditions from the road system itself. In closing, they argue for systems thinking as a means to better protect adolescents on the road and pinpoint improved data systems as one means of implementing systems thinking in road safety efforts generally.

2.6. Road system design

The design of new road environments is perhaps one area where human factors and systems thinking can have an immediate impact. This is because there are a range of existing system design and evaluation methods that can be used to inform design, and also because there is clear evidence available which demonstrates how systems thinking-based design approaches have created more efficient designs in other safety critical systems. Candappa and colleagues (an exploration of alternative intersection designs in the context of safe system) apply a framework to consider the extent to which a number of candidate intersection designs are compatible with the safe systems philosophy. A key focus is to work towards the goal of providing a practical approach that can be used by road authorities to consider infrastructure design in the context of the safe system. The Kinetic Energy Management Model (KEMM) was used as a basis to define practical design principles that could be used to achieve intersections with high levels of safety. The underpinning model focuses specifically on the safe management of kinetic energy in the road-transport system in terms of five layers: exposure, crash risk per exposure, kinetic energy per exposure, transfer of kinetic energy to human, and biomechanical tolerance of humans. The risk factors in these layers are then analysed in relation to the system components: human, roads and roadsides, the vehicle and speed. Using these combined inputs the authors define several safe intersection design principles deemed necessary for safer intersections. Criteria were developed to establish the extent to which a range of candidate intersection designs were compatible with the design principles. The authors conclude that few current intersection designs align well with the design principles identified, and that persisting with many designs in their current form limits the possibilities for achieving the safe system ambition of eliminating the risk of fatal and serious injury intersection crashes in the long term.

Cornelissen, Salmon, Stanton and McClure (assessing the 'system' in safe systems-based road designs) take a very different approach to intersection safety and argue that methodologies from the discipline of Human Factors and Ergonomics have a key role to play in the design and evaluation of road environments. In doing so they present an evaluation of two intersection environments using the Strategies Analysis Diagram (SAD; Cornelissen et al., 2013) method from the Cognitive Work Analysis framework (CWA; Vicente, 1999). The SAD works by identifying the range of possible behaviours within a given system based on a model of the constraints influencing behaviour within that system. The evaluation involved applying SAD to identify likely road

user behaviours in an existing intersection located in the south-east suburbs of Melbourne and a new 'cut-through' future intersection design concept. Importantly the analysis considered different forms of road user including drivers, cyclists, motorcyclists and pedestrians. Cornelissen et al's analysis demonstrates that, despite being markedly different in layout and structure, the constraints influencing road user behaviour in both environments are similar. Despite this, Cornelissen et al. report that the cut-through intersection is likely to produce emergent behaviours that were not anticipated by designers and could be problematic. They also conclude that incompatibilities between infrastructure, vehicles and different forms of road user present within the existing intersection have not been dealt with in the new cut-through design. In closing, Cornelissen et al. argue that integrating systems analysis methods with current intersection design processes will lead to road environments that better support the behaviour of all road users.

Stevens and Salmon (safe places for pedestrians: using cognitive work analysis to consider the relationships between the engineering and urban design of footpaths) also apply CWA to analyse the impact of road design but in the context of pedestrian safety. Bringing together the disciplines of urban design and human factors this study recognises two main challenges that have inhibited the ability of footpaths to be significant and safe community locations. Firstly, they are often dangerous locations with sizable numbers of pedestrian fatalities, and secondly, the footpath allocation within roadway corridors is often not an appealing or hospitable place for pedestrians. Urban footpaths remain poorly designed and ill-considered extensions of the roadway environment, and key aspects of footpath design such as safety, engineering, and sense of place are often pursued in silos with little consideration given to how designing for sense of place impacts safety and vice versa. Stevens and Salmon applied a systems analysis and design framework to develop a design template for an 'ideal' footpath system that embodies both safety and sense of place. Using the first phase of the CWA, Work Domain Analysis, the authors outline a model of footpaths as safe places for pedestrians. This model was subsequently used to assess two existing footpath environments to determine the extent to which they meet the design requirements specified by their model. In the paper there are many instances highlighted where the existing footpaths both meet and fail to meet the design requirements specified. The paper provides a novel design template that can inform new footpath designs and highlights the interdependency of many issues that have historically been managed in isolation within discipline areas. The authors note the importance of further testing the application of CWA to urban design on a larger scale.

2.7. Distraction

Driver distraction currently represents a significant threat to road safety in most jurisdictions. In Australia, for example, nearly two-thirds of crashes resulting in hospital admission involve driver inattention (Beanland et al., 2013). In the United States, distraction was identified as a causal factor in 16% of the fatal crashes that occurred during 2008 (NHTSA, 2009). Young and Salmon (Sharing the responsibility for driver distraction across road transport systems) use Rasmussen's risk management framework and accompanying Accimap method to investigate the extent to which a systems thinking approach is currently being applied to the problem of driver distraction. First, they present an ActorMap depicting the individuals, groups, and organisations that have some responsibility for creating and/or mitigating the problem of driver distraction. Second, based on a review of the literature they place the currently known sources and enablers of driver distraction across six levels of the road transport system ranging from the road environment and road users to road safety agencies and government. Third, they use Rasmussen's levels to speculate on what a systems thinking approach to driver distraction might entail, showing how activities across the overall road system can combine to create the design of distraction proof in-vehicle devices. In conclusion Young and Salmon argue that driver distraction is a systems issue requiring systems thinking-based solutions. Their analysis shows that, whilst there are multiple individuals and organisations that play a role in enabling and preventing it, the prevalent approach to investigating and managing distraction has been driver-centric. In closing they argue that the adoption of a systems thinking approach will help to integrate and improve existing knowledge and traditional interventions and will enhance management of distraction.

Lansdowne, Stevens &Walker (multiple driver distractions: a systemic transport problem) take a different approach and highlight that a prominent feature of the distraction literature is the primacy given to an individual device, yet we are now dealing with multiple devices and multiple means by which cognitive resources may be eroded. On this basis the authors argue that driver distraction therefore becomes a systems problem that requires a shift from considering component parts such as mobile phones and linear chains of cause and effect, to a focus on more complex and sophisticated forms of new technology. A primary concern here is considering how the human and technological components interact in an environment now where once isolated systems are becoming integrated into ever more complex in-vehicle networks. A systematic review of driver's engagement with Multiple Additional-to-Driving (MAD) tasks was undertaken to ascertain the associated impacts on driving and the interconnections between sources of distraction, drivers and the wider context. In almost all cases, undertaking MAD tasks was found to result in detrimental reductions in primary task performance. The authors propose a systematic model of multiple attentional distraction that is expressed as a representation of the driver's current task demands and builds on the concepts developed in Fuller's (2005) Task–Capability Interface (TCI) model. These factors are composed of the primary task, driving; one or more non-primary tasks (notably the multiple attentional distractions); the pertinent environmental factors; and the driver's characteristics. The authors conclude that it is possible to generate systemic testable performance resource functions that could be used to represent the evolving, adaptive, and complex nature of MAD tasks in a way that is able to capture emergent phenomenon that would otherwise be difficult to detect.

3. Summary and key take home messages

In our view, adopting new systems thinking approaches in road safety research and practice has the potential to aid the design and operation of safer road transport systems and to facilitate new reductions in road trauma. The contributions presented in this special issue cover a wide range of road safety issues and involve the application of various systems thinking models and methods. Taken together these contributions demonstrate, first, that systems thinking is beginning to gain traction in road safety research, and second, that systems thinking applications have the potential to significantly advance the road safety knowledge base. Each article engenders important take-home messages for road safety and future road safety research and practice. These have been integrated into the following key messages:

- There are various systems thinking models that appear applicable to road safety applications; however, few have been applied in this context;
- The application of systems thinking models and methods affords the opportunity to take a far more holistic approach to road safety;

- Existing systems thinking models and methods should be considered for future road safety research and practice applications;
- The knowledge base on the causes of key road crash causing behaviours is heavily oriented to factors around drivers, their vehicles, and the road environment;
- A key factor preventing systems thinking applications in road transport is the lack of appropriate crash data systems. The development of systems thinking-based crash data collection and analysis systems is a key future research requirement;
- Although they contain elements of systems thinking, contemporary road safety strategies are fundamentally different to systems thinking approaches;
- Despite their clear differences, existing approaches can usefully be extended to incorporate systems thinking;
- Focussing on the interactions between road users is a key future research requirement. For example, focussing on road user interactions when managing their own safety and that of other road users will significantly advance the knowledge base;
- Suites of countermeasures that target different aspects of the road transport system together (e.g. road users, vehicles, road environment, training, and education) are more effective than interventions focussed on one component alone;
- Key road safety issues such as driver distraction are systems problems, not individual road user problems;
- There are multiple stakeholders who share the responsibility for key road safety issues such as young drivers and distraction. These stakeholders reside at all levels of Rasmussen's framework;

Countermeasures designed to prevent road trauma are likely to be more effective if they focus on factors at all levels of road transport systems and interactions between components, compared to those focussing on individual components themselves. This 'fix the system' approach will likely be more effective than the prevalent 'fix the driver' approach;

- Approaches to system design that eliminate hazards from the road system are likely to be more effective than attempting to eliminate risk taking behaviours;
- Existing road environments and road design concepts do not align well with systems thinking principles; and
- There is a pressing need to integrate systems analysis and design methods within road design and evaluation processes.

The title of this editorial was arrived upon some time ago and represented a desire of the authors from the outset to determine the extent to which systems thinking approaches are being applied in road safety. Following receipt of the contributions presented it appears that we are neither 'miles away', nor is a full systems thinking approach 'just around the corner'. Rather, a great deal of groundwork has been laid, and significant applications are being undertaken. In our view this bodes well for road safety, and further signifies the ability of those in this domain to initiate new thinking and practice. Further applications of systems thinking are currently being undertaken by the co-authors and their collaborators, and new applications are encouraged.

As a final point it is worth noting that all of the contributions to this special issue describe research applications and not practice applications. Indeed, it is questionable whether systems thinking research has yet been implemented in road safety circles. The challenge for the road safety community (researchers, practitioners, stakeholders) now is not only to further investigate systems thinking applications in road safety research, but also to translate research of this kind into practice. We hope that this special issue has provided some impetus for this by clarifying some of the approaches available and the potential contribution of systems thinking.

In closing we would like to thank all of the authors who have contributed to this special issue and the many reviewers who served to refine the papers presented. We hope that road safety researchers and practitioners will find the contributions enlightening and inspiring, and that new systems thinking applications emerge as a result.

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