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System theory and safety models in Swedish, UK, Dutch and Australian road safety strategies

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ABSTRACT

Road safety strategies represent interventions on a complex social technical system level. An understanding of a theoretical basis and description is required for strategies to be structured and developed. Road safety strategies are described as systems, but have not been related to the theory, principles and basis by which systems have been developed and analysed. Recently, road safety strategies, which have been employed for many years in different countries, have moved to a 'vision zero', or 'safe system' style. The aim of this study was to analyse the successful Swedish, United Kingdom and Dutch road safety strategies against the older, and newer, Australian road safety strategies, with respect to their foundations in system theory and safety models. Analysis of the strategies against these foundations could indicate potential improvements. The content of four modern cases of road safety strategy was compared against each other, reviewed against scientific systems theory and reviewed against types of safety model. The strategies contained substantial similarities, but were different in terms of fundamental constructs and principles, with limited theoretical basis. The results indicate that the modern strategies do not include essential aspects of systems theory that describe relationships and interdependencies between key components. The description of these strategies as systems is therefore not well founded and deserves further development.

1. Introduction

Road traffic injury is listed in the top ten major causes of mortality and morbidity worldwide (WHO, 2010). It is estimated that more than 1.2 million people die as a result of road traffic crashes and some 50 million are injured per annum (WHO, 2009). Across the world, road safety strategies are therefore developed, implemented and evaluated against different kinds of road related fatality and injury estimates (Johnston, 2010). It has been pointed out that road safety strategies are all implemented into a social technical system, *"Complex systems cannot be understood by studying parts in isolation. The very essence... lies in the interaction between parts and the overall behaviour that emerges from the interactions..."* (p293). This implies that if a strategy does not consider the system as a whole it is likely to fail (Ottino, 2003). However, the road traffic system is complex (Salmon et al., 2012) and therefore needs to be modelled before it can be understood and properly structured, in order to generate, for example, road safety strategies (Kaposi and Myers, 1994).

Following the introduction of recent road safety strategies, such as the Vision Zero in Sweden (Larsson et al., 2010), the Tomorrow's roads: safer for everyone in the U.K. (Department for Transport, 2000) and Sustainable Safety in the Netherlands (Wegman and Aarts, 2006; Wegman et al., 2008), a subsequent or continuing improvement in road safety has been observed. The number of people killed per capita from 2000 to 2011 has declined by approximately 4.85% per annum in Sweden, the United Kingdom (UK) and the Netherlands during this period, as shown in Fig. 1. A similar reduction has not been observed in Australia, where the number of people killed per capita only decreased by about 3.3% per annum despite *The National Road Safety Strategy: 2001–2010.* As a result, a new *Australian Road Safety Strategy: 2011–2020* has been agreed (Australian Transport Council, 2011), which more closely aligns with the Swedish and Dutch strategies.

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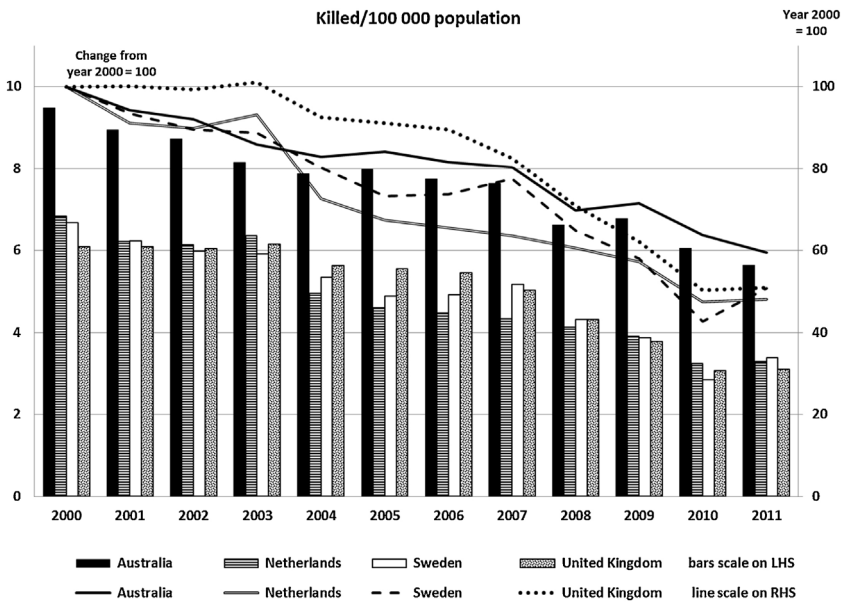

Fig. 1. Recent history of road safety outcomes in four countries. LHS = left hand scale, RHS = right hand scale. The *x*-axis represents the years 2000 to 2011. The curves represent normative data across the four countries.

'Models' are simplified descriptions or representations to assist understanding. They create a mental picture, facilitate questioning, establishing rules, checking, evaluation, analysis, identifying and assessing countermeasures and communication (Kjellén, 2000; Hughes et al., 2014). Many different types of model have been applied to identifying and managing risks, but not all of them have been applied to road safety (Hughes et al., 2014).

Systems concepts are highly influential in various diverse domains to improve safety, although the term 'system' is widely, but inconsistently used (Waterson, 2009), and it has not been thoroughly or widely applied to road safety (Salmon et al., 2012). Systems are operating entities comprising discrete components which transform input to output for a purpose (Hughes et al., 2014). According to systems theory, systems exist when there are interdependent, but related components achieving a valued pre-set objective, purpose or function. System theory has been thoroughly and scientifically developed over a long time to explore complex processes of transforming input to output for a purpose (Von Bertalanffy, 1968; Perrow, 1984; Leveson, 2004, 2011; Waterson, 2009; Wilson, 2014a,b). Safety in complex operations and situations including aviation, rail transport, nuclear power and health (Waterson, 2009) and aerospace, production industry, water supplies, and the military (Leveson, 2011) has benefited from application of systems theory and techniques.

This study investigates the basis of five road safety strategies based on systems theory and safety models. While Larsson et al. (2010) describes the Vision Zero as based on system theory, they claim that there are very few references of systems theory being applied to other road safety strategies. Furthermore, they describe road safety strategies to be simplistic and limited and therefore inconsistent with system theory. Whether this is true or not needs to be scrutinised. However, road safety strategies have previously been compared by Koornstra et al. (2002) who found both considerable differences and substantial similarities between successful strategies.

1.1. Swedish, UK, Dutch and Australian road safety strategies

The key components of the Swedish, UK, Dutch and two Australian Road Safety Strategies analysed in this paper are summarised in Table 1. The strategies are widely different in the way they are presented and the additional material included as road safety, transport or institutional background or for implementation. The Swedish Vision Zero uses points for 'long-term guideline and traffic safety structure', although there are multiple descriptions of Vision Zero which differ (Ministry of Transport and Communications, 1997; Tingvall and Haworth, 1999; Tingvall and Lie, 2001; Wegman et al., undated; Larsson et al., 2010). The UK strategy is based on main themes, while the Dutch focus on five principles with three 'Risk factors' and the Australian Road Safety Strategy uses 'key cornerstones' and 'guiding principles'. In the present study, we have regarded all of them to be 'Key Components', according to system theory, as described below.

The aim of this study was to analyse the Swedish, UK and Dutch road safety strategies against old and new versions of the Australian road safety strategy, with respect to their foundations in system theory and safety models.

2. Methods

With a starting point in system theory and safety models and the connection between those, a review of the five identified road safety strategies was carried out, as illustrated in Fig. 2.

2.1. System theory

Several terms are used in discussions about systems including system, systems theory, systems approaches and systematic processes (Hughes et al., 2014). System theory describes that systems exist when there are interdependent but related components achieving a valued pre-set objective (or purpose or function) (Von Bertalanffy, 1968; Perrow, 1984; Leveson, 2004, 2011). Systems may be supported further by principles, and based on theories and information applicable to the situation (such as road safety or organisations). Consequently, the fundamental constructs of system theory are: Key Components, Relationships, Objectives and Interdependency, in addition to principles and theoretical basis.

Fig. 2. A model of the design of the present study.

Table 1
Key components of Swedish, UK, Dutch and Australian road safety strategies.

Strategy	Key components
Sweden: *Vision Zero* (adapted from: Ministry of Transport and Communications, 1997; Tingvall and Haworth, 1999; Tingvall and Lie, 2001; Wegman et al., in-press; Larsson et al., 2010)	Vision Zero is the philosophy and long-term guideline and traffic safety structure 1. Human life and health are paramount so no one should be killed or seriously injured as a result of a traffic accident 2. Life and health should not be allowed in the long run to be traded off against the benefits of the road transport system, such as mobility 3. Vision Zero is an ethical approach to safety and mobility 4. The emphasis is moved away from enhancing the ability of road users to cope with an imperfect system 5. Traffic accidents cannot always be avoided, since people sometimes make mistakes 6. Accidents must be prevented from leading to fatalities and serious injuries by designing roads, vehicles and transport services in a way that someone can tolerate the violence of an accident, without being killed or seriously injured 7. Everyone shares responsibility for making traffic safer: politicians, planners, road maintenance organisations, municipalities, transport service providers, vehicle manufacturers, and road users 8. Road safety targets are an integral part of the philosophy
United Kingdom: *Tomorrow's roads: safer for everyone* (Department for Transport, 2000)	Ten main themes, each clearly elaborated in a strategy, a set of specific actions or points of attention, and a timetable for their implementation 1. Safer for children 2. Safer drivers training and testing 3. Safer drivers—drink, drugs and drowsiness 4. Safer infrastructure 5. Safer speeds 6. Safer vehicles 7. Safer motorcycling 8. Safer pedestrians, cyclists and horse riders 9. Better enforcement 10. Promoting safer road use Note: This strategy was superseded by the Strategic Road Safety Framework in 2011, which was less clear in describing actions under categories
Netherlands: *Sustainable Safety* (Wegman and Aarts, 2006, Wegman et al., 2008)	The strategy is based five principles: 1. Functionality of Roads—Monofunctionality of roads as either through roads, distributor roads, or access roads, in a hierarchically structured road network 2. Homogeneity of mass and/or speed and direction—Equality in speed, direction and mass at medium ad high speeds 3. Predictability of road course and road user behaviour by a recognisable road design—Road environment and road behaviour that support road user expectations through consistency and continuity in road design 4. Forgivingness of the environment and of road users—Injury limitation through a forgiving road environment and anticipation of road user behaviour 5. State awareness by the road user—Ability to assess one's task capability to handle the driving task Risk factors: 1. Speed 2. Mass and Protection 3. Road User Factors: Lack of driving experience, Psycho-active substances: alcohol and drugs, Illnesses and ailments, Emotion and aggression, Fatigue, Distraction
Australia: *National Road Safety Strategy: 2011–2020* (Australian Transport Council, 2011)	Key cornerstones: 1. Safe Roads—Roads and roadsides designed and maintained to reduce the risk of crashes occurring and to lessen the severity of injury if a crash does occur. Safe roads prevent unintended use through design and encourage safe behaviour by users 2. Safe Speeds—Speed limits complementing the road environment to manage crash impact forces to within human tolerance; and all road users complying with the speed limits 3. Safe Vehicles—Vehicles which not only lessen the likelihood of a crash and protect occupants, but also simplify the driving task and protect vulnerable users. Increasingly this will involve vehicles that communicate with roads and other vehicles, while automating protective systems when crash risk is elevated 4. Safe People—Encourage safe, consistent and compliant behaviour through well-informed and educated road users. Licensing, education, road rules, enforcement and sanctions are all part of the Safe System Guiding principles: 1. People make mistakes. Humans will continue to make mistakes, and the transport system must accommodate these. The transport system should not result in death or serious injury as a consequence of errors on the roads 2. Human physical frailty. There are known physical limits to the amount of force our bodies can take before we are injured 3. A 'forgiving' road transport system. A Safe System ensures that the forces in collisions do not exceed the limits of human tolerance. Speeds must be managed so that humans are not exposed to impact forces beyond their physical tolerance. System designers and operators need to take into account the limits of the human body in designing and maintaining roads, vehicles and speeds 4. Shared responsibility and corporate responsibility. Responsibility for road safety is shared by all Intervention priorities (a series of management functions focused on achieving results): 1. Adopting a results focus for the implementation of the strategy 2. Ensuring effective coordination of activity among all key players 3. Ensuring rules are in place to back the commitment to road safety 4. Identifying funding and prioritising the allocation of resources to safety 5. Promoting a shared responsibility for road safety 6. Monitoring and evaluating road safety progress 7. Investing in research and development, and knowledge transfer 8. Continuing to monitor road safety technology trends and advances domestically and internationally.

Table 1 (*Continued*)

Strategy	Key components
Australia: *The National Road Safety Strategy 2001–2010* (Australian Transport Council, 2000)	Strategic objectives: 1. Improve road user behaviour; 2. Improve the safety of roads; 3. Improve vehicle compatibility and occupant protection; 4. Use new technology to reduce human error; 5. Improve equity among road users; 6. Improve trauma, medical and retrieval services; 7. Improve road safety policy and programmes through research of safety outcomes; and 8. Encourage alternatives to motor vehicle use Principles: 1. The road toll should not be accepted as inevitable 2. The priority given to road safety should reflect the high value that the community as a whole places on the preservation of human life and the prevention of serious injury. The community, in turn, has an essential role in the development of positive approaches to safe road use, a role which requires its widespread support and participation 3. There is a balance to be struck between furthering many legitimate community objectives and increasing exposure to the risk of road trauma: ¬ Health and environmental benefits exist through increased walking and cycling ¬ Economic and employment benefits are associated with greater road freight cartage and other vehicular traffic ¬ Quality of life benefits exist in affording personal mobility to young and older people ¬ Smaller cars and motorcycles offer consumer and potential environmental benefits 4. Seek to realise these community objectives by making travel safer. Recognising that safety must be integrated with other legitimate community objectives, all safety measures that can be justified in terms of overall community benefits should be implemented

Systems approaches are processes and techniques for investigating and improving systems as a whole. Accidents are seen as the result of unexpected, uncontrolled relationships between different parts of the system, rather than having a simple cause and effect relationship. Systems approaches provide deeper understanding of how dynamic, complex system behaviour contributes to accidents (Underwood and Waterson, 2013). Compared to simpler analysis, the systems approach is comprehensive, rigorous, founded in theory and proven in practice. Systems approaches are different from general systematic techniques, which are simply thorough and documented processes, without necessarily having a basis in theory or evidence, or demonstrated value in practice.

In this study, a normative approach compared road safety strategies against system theory because of the description that road safety strategies are 'systems' based, and systems concepts are well founded in theory and thoroughly proven in practice. The criteria for assessment are defined based on systems theory (Von Bertalanffy, 1968; Perrow, 1984; Leveson, 2004, 2011) to assess whether the five selected road safety strategies were consistent with systems theory. Hence, these criteria were: *Key Components*, *Relationships*, *Objectives* (or purpose) and *Interdependency*, since they represent the fundamental elements based on systems theory. Two additional criteria: *Principles* and *Theoretical Basis* were also included as they are included in some systems analysis.

Key Components are the constituent parts which comprise the systems that are both essential for the system to operate and to make a contribution to achieving the intended purpose or outcome of the system. *Relationships* are descriptions of the type of connection between key components and how each individual component affect, or are affected by other parts. *Relationships* describe how the key components interact, for example physically, electrically, by information, or by some other means. *Objectives* are descriptions of what is intended to be achieved. *Interdependency* is a description of the contribution of the key components to achieving the purpose and/or the degree to which the purpose requires the key component to achieve the purpose. So, *Interdependency* recognises whether the objective is only achieved when all of the key components contribute, whether the objective is reduced or threatened if any one of the key components fails to operate as required, and the complementary benefits of synergies where the whole is greater than the sum of the parts. *Principles* are descriptions of the fundamental propositions which underlie the rationale behind the strategy. A *Theoretical Basis* exists when the strategy is grounded in a thoroughly proven rationale supported by evidence. While there is substantial evidence for road safety countermeasures, this criterion also considers whether the underlying rationale of the strategy itself is based in theory.

No assessment was made as to the degree to which any of the strategies met the criteria. Such assessment is subjective and dependent on the personal opinion of assessors. For instance, the original authors of the strategies presumably considered the key components to be complete, whereas others may suggest that additional, more valuable components should be included. Different strategies may also describe the components according to quite different types and yet not be invalid. The key components for the later Australian strategy were roads, vehicles drivers and speed; the UK strategy components focused primarily on particular categories of road user; while the most important components Swedish and Dutch strategies were principles.

2.2. Safety models

A model describes something, in order to provide information in a simplified form. For example, models can be physical, visual, mathematical, etc. Models may describe components, processes, organisations, events, dependencies, factors, causation, etc. In the present study, safety models illustrate safety also as the prevention of harm. In the occupational industrial and other settings safety models are common.

Models of safety are not commonly categorized. However, in a study by Hughes et al. (2014), an attempt for quantitative analysis identified seven categories of model type: (1) *Component*, (2) *Sequence*, (3) *Intervention*, (4) *Mathematical*, (5) *Process*, (6) *Safety Management*, and (7) *System*. These types cover the majority of models describing safety at a high level. The Hughes et al. (2014) study compared different models according to purposes, usage, strengths, weaknesses and relevance to specific circumstances. Since most of the models have some acceptance in practice, they may be useful for the assessment of the use in road safety strategy, taking into account the context and the need of the user. Some safety models used in other domains include a wider context and greater breadth of factors affecting safety with the

Table 2
Similarities and differences between Swedish, UK, Dutch and two Australian Road Safety Strategies with respect to systems theory.

Strategy	Fundamental constructs				Supporting information	
	Key Components described	Relationships described	Objectives described	Interdependency described	Principles described	Theoretical Basis
Sweden: *Vision Zero*	Eight guiding principles Fifteen headings	No	Yes	No, but implied	Yes	Not described
United Kingdom: *Tomorrow's roads: safer for everyone*	Ten main themes	No	Yes	No, but implied	No	Observation and analysis, research
Netherlands: *Sustainable Safety*	Five principles Three high level risk factors	No	Yes	No, but implied	Yes	Road safety theory, observation and analysis, research
Australia: *National Road Safety Strategy: 2011–2020*	Four guiding principles Four 'cornerstone areas'	No	Yes	No, but implied	Yes	Observation and analysis, research
Australia: *The National Road Safety Strategy 2001–2010*	Four principles Eight strategic components.	No	Yes	No, but implied	Yes	Observation and analysis, research

potential to be applied to improve road safety. Additional factors, such as the effect of organisational culture, emergency responses, the health system and economic influences on road safety could also be included in road safety strategies.

More specific or detailed models exist, particularly at the micro level for assessing the effects of individual issues or countermeasures, but they are not addressed in the present study. Models of event chains or sequential work, activity or process are appropriately applied to specific events or circumstances as they are rich in detail. However, to create such models applicable for road safety, strategies become overwhelmingly complex (Greibe, 2003).

2.3. Safety strategies

Safety strategies describe general directions, plans or specific actions by which safety is improved. The purpose of industrial safety strategies is to reduce the loss of human life injury and financial costs. The objectives of road safety strategies are to reduce the impacts of road crashes, particularly the number of people killed or seriously injured. In road safety, occurrences with negative consequences are called 'crashes', to separate the implication of randomness of occurrence and inevitability (Evans, 2004). Industrial, occupational and other safety literature generally uses the term 'accident' when a loss occurs and 'incident' or 'near-miss' when an occurrence nearly results in an accident.

The present study assessed whether the five selected road safety strategies were consistent with both system theory and seven different generic types of model (Hughes et al., 2014). Additionally, the results may suggest whether system theory and different types of model, or parts thereof, may be applied to improve road safety strategies.

3. Results

Table 2 summarises the Swedish, Dutch, UK and Australian road safety strategies according to the fundamental constructs of system theory. The strategies were analysed against (i) the key attributes of systems, and (ii) the additional descriptions which may be included in strategies and relevant to systems.

In general terms, the strategies in Table 2 have more similarities than differences, but are not consistent with system theory descriptions. All the strategies describe 'components' although of different types, but it is not evident that these are complete and other key components may be applicable. Relationships are not recognised in the strategies and interdependency is not explicitly described.

The key components described in the studied road safety strategies are generally different to those in system theory, which typically describe components as physical entities, such as operators and machines. Two aspects of system theory are not evident in any of the strategies; the relationships between components or interdependency of the components. While there is a theoretical basis in observation and research of many individual factors and countermeasures within the strategies, there are no theoretical foundations in either system theory or crashes.

Table 3 summarises the Swedish, Dutch, UK and Australian road safety strategies according to types of model used in other safety domains.

No assessment was made at determining the degree to which any of the strategies met the system criteria, since an objective measure was too difficult to define. However, it is evident that some attributes were clearer and stronger than others, such as the components in the Australian road safety strategies, as opposed to Sustainable Safety where the risk factors weakly describe key components, perhaps barely meeting the assessment criteria, although reflecting similar components in other strategies. However, all the strategies, except for the UK strategy, included strong and clear descriptions of principles.

Many similarities between the strategies in terms of the type of safety models used exist. All strategies contain descriptions of components, interventions (or countermeasures) and some form of quantitative analysis as a foundation. The descriptions within these categories are, however, different. By being so, all the strategies become multifaceted, which may be a strength in terms of robustness of approach or a weakness in terms of lack of clarity. None of the strategies are described in terms of event chain or sequence; work, activity or process; safety or risk management system or process; or system type of safety model. However, for the purposes of describing whole systems or strategies the use of these models is inappropriate due to complexity.

The translation of strategies into practice is crucial for success and is clearly implicit in the strategies, with various aspects being described. At least some aspects of strategy implementation: scope, individual activities, responsibilities and consequences, are included in all the strategies. Each of the ten main themes in the UK strategy includes an 'Action Plan' for implementation over various timeframes, including the establishment of a Road Safety Advisory Panel and evaluation. The earlier Australian strategy includes requirements for actions plans to be developed, together with monitoring and reporting of implementation. The current Australian strategy thoroughly includes a section covering *Results focus*, *Linkages and synergies*; *Co-ordination*; *Legislation, regulation and standards*; *Funding and resource allocation*; *Promotion and education*; *Accountability*; *Monitoring and evaluation*; *Capacity development, research and knowledge transfer*; and *Training and*

Table 3
Assessment of type of safety model for Swedish, UK, Dutch and two Australian Road Safety Strategies.

Strategy	Type of safety model						
	Component[1] or unit	Event chain or sequence	Intervention	Work, activity or process	Quantitative analytical	Safety or risk management system or process	System
Sweden: *Vision Zero*	Eight guiding principles	–[2]	12 primary interventions	–	Based on crash record	–	–
United Kingdom: *Tomorrow's roads: safer for everyone*	Ten main themes	–	Numerous actions	–	Based on crash record	–	–
Netherlands: *Sustainable Safety*	Five principles. Three key risk factors (six sub-factors)	–	Generally described with implementation characteristics	–	Based on crash record	–	–
Australia: *National Road Safety Strategy: 2011–2020*	Four cornerstones. Four guiding principles	–	Eight intervention priorities	–	Based on crash record	–	–
Australia: *The National Road Safety Strategy 2001–2010*	Eight strategic components. Four guiding principles	–	Eight strategic components	–	Based on crash record	–	–

Notes: [1] Components or units in safety models are normally physical (such as human, machine, environment), rather than intangible issues or concepts.
[2] "–" Not described in the available literature.

staff development. Implementation issues warrant a more thorough analysis regarding its scope, application and effectiveness, which is beyond this study and not included in any of the strategies analysed.

4. Discussion

Road safety is a specific subject within the broad, general topic of safety considered for many different situations and scenarios. Many analyses and concepts used in road safety have been drawn from wider safety literature and experience. However, a wider analysis of the many models described in safety literature may reveal more concepts, principles or practice which can be applied to road safety strategies.

Road safety strategies are described as systems, but have not been related to the theory, principles and basis by which systems have been developed and analysed. Examples are the application of a modern systems analysis approach, drift into failure (DIF), to changes in road safety as a whole (Salmon et al., 2012) and the application of systems approach to the specific road safety problem of level crossings (Read et al., 2013), but the theory has not been applied to road safety strategies.

4.1. Implications of systems theory for road safety strategies

System theory is a thorough and scientifically based analysis of complex systems, and overcomes the weaknesses of a simplistic reductionist view, which assesses individual components in isolation. In the road strategies analysed, the constituent components are described in isolation without any representation of individual or joint contribution to the outcome as a whole. In the same way, there is no appreciation of the relationships between components, the effect of each on the others or the interdependency of all key components contribution of all key components to the outcome.

The five studied road safety strategies are described in different ways, using different language, so the consistency against systems theory criteria is somewhat uncertain. For instance, the 'headings' in *Vision Zero*, 'themes' in *Tomorrow's roads: safer for everyone*, 'principles' and 'risk factors' in *Sustainable Safety*, 'cornerstone areas' in the Australian *National Road Safety Strategy 2011–2020*, and 'strategic components' in the Australian *National Road Safety Strategy 2001–2010* are all quite different descriptions of key components required by systems theory.

The analysis failed to find proof that the road safety strategies have a solid foundation in system theory. If the strategies were founded in system theories or fully within safety models, the consistency between the fundamental constructs of the strategies would be expected to be much greater. If road safety strategies are to be described as safety systems, their development should start with a basis in system theory and use existing proven safety models (including those outside of the road safety area). Applying systems theory would more clearly identify the components which make up the strategy and the interrelationships between the components. Systems theory and practice from other contexts may also provide opportunities to improve road safety by considering it to be part of a larger (open) system, rather than a small (closed) system, and by considering the effect of any change in parts of the system (e.g., components, actors, or countermeasures) on other parts of the system. Such a thorough application of system theory and practice from other contexts may provide opportunities to improve road safety.

Moreover, there are fundamental constructs of system theory that have been found to be valuable in other contexts, which potentially can be applied in road safety strategies to improve future outcomes. For example, the Dutch Sustainable Safety recognises monofunctionality of roads as being an important concept for road design that is not evident in other strategies. This approach recognises the interdependency between components in achieving the whole of system outcome, and individual relationships between components in understanding the system operation.

A road safety strategy based on understanding of systems would describe the interrelationships between components and how they synergistically work together so that the whole is greater than the sum of the parts. Such a strategy consistent with system theory would include the fundamental attributes: *Key Components*, *Relationships*, *Objectives* and *Interdependency*, some of which are already described by the five road safety strategies considered. *Principles* and a *Theoretical Basis* may also be added. Given that system theory and approaches have successfully been applied to improve safety in other domains, Sustainable Safety and Vision Zero could therefore clearly identify the key components. All of the strategies studied

may be improved by adding components, as included in other safety models from other domains.

To be consistent with system theory, the road safety strategies studied would describe the relationships between the constituent parts. Doing so would describe how every individual component is affected by every other part. For instance, there is currently no description about how driver safety (competence and behaviour) is affected by safe road designs. Interdependence could be included by describing how the outcomes of the strategy would be affected if any part was excluded.

4.2. Potential of alternative safety models for road safety strategies

The strategies investigated have consistencies with other general types of safety models, although this may be an accidental but rational development following previous strategies. The different strategies use different categorisations or descriptions for the components and principles, although this does not represent a fundamentally different way of designing the structure of the strategies which reflect differences in language and focus. Safety models used in other domains describe additional components which could be included in the road safety strategies studied.

The development of these strategies is not clearly described, so the justification for the components which are either included or excluded is not evident. Other types and safety models include other components not included in the road safety strategies analysed. Road safety strategies may be more valuable with the inclusion of responses to social factors, such as culture, or wider environmental influence, such as economic factors (Haddon, 1980). Other safety policy measures cover the health system for emergency response, medical treatment and rehabilitation (Hawksley, 1999), which could also be included in the studied road safety strategies.

Other approaches to improving safety which have been applied elsewhere, may also be applied to road safety including safety culture and continuous improvement. Safety culture (Hale and Hovden, 1998) is described as a characteristic, property or component of systems, rather than a model in itself (Hughes et al., 2014). Continuous improvement (Weinstein, 1996; Standards Australia and Standards New Zealand, 2001) has a long history of development and successful application as a process to improve systems, products, processes or services.

The benefits of thorough implementation are reported in several safety models and widely used (Weinstein, 1996; Standards Australia and Standards New Zealand, 2001), without being part of any specific model type or described in system theory. However, efficient implementation is essential for any safety strategy to be effective and should therefore be included in any road safety strategy.

Various other safety models could be applied to road safety strategies by developing and applying a safety management system approach (Standards Australia, 2006), developing and applying safety culture improvement, and/or applying risk management (hazard identification, assessment and countermeasure deployment) to situations and projects (Glendon and Waring, 1997; Rasmussen, 1997). Two other safety models; event chain or sequence, and work, activity or process are normally applied at a detailed level rather than to systems as a whole. Therefore, these types of model do not appear to be readily applicable to high level road safety strategies.

4.3. Further potential improvements to road safety strategies

The introduction of a road safety strategy and its contribution to a reduction in road trauma was not the objective of this investigation. Changes in road trauma are potentially subject to a myriad of factors and no assessment of the contribution of the strategies to the changes has been found in literature, except by implication as strategies are referred to.

The four countries from which the analysed road strategies originated may share many similarities in terms of culture, vehicle fleet, law, etc. However, the Netherlands and the UK have much greater population densities, while Australia and Sweden have much longer and more remote travel. Aspects such as driver behaviour may have as many similarities as differences. Some factors, such as Australia's high population growth rates may be peculiar to one location, but not others.

All the strategies describe the objectives' fundamental constructs and supporting information, apparently being developed in recognition of observations of context and road safety history (although the road crash measures for the basis of the strategies and objectives vary). However, the details of these are inconsistent, so it may be that the components and objectives clarify the strategy to focus effort on the most important issues. In such a case, efficacy may be maximised when the greatest benefits are achieved for effort applied.

Principles which underlie safety models or system theory can be explicitly stated or implicit, as if they are naturally understood without the need to be clearly described. The five road safety strategies describe certain principles explicitly, as summarised in Table 1, however they also include other concepts implicitly. The number of people killed is the most commonly used and promoted metric of road safety. Ministry of Transport and Communications (1997) note "*. . . eventually no one will be killed or seriously injured within the road transport system . . .*" for Vision Zero, while the UK strategy proposes "*. . . a 40% reduction in the number of people killed or seriously injured in road accidents . . .*" (p4). The other studied strategies use fatalities and serious injuries as the predominant measure of consequences. Fatalities and serious injuries are also related to exposure measures, such as population as a secondary measure for comparison purposes. The ratios which result can provide indications over time, and comparative data between countries (Koornstra et al., 2002; Wegman et al., undated).

It is not evident that these strategies have been developed based on scientific theory, such as system theory, and a proven method, such as the system approach. Similarly, the development and selection of subordinate policies and programmes is not described to demonstrate that the implementation is thorough and justified. Accordingly, a robust scientific basis for these strategies has not been described, with the exception of the benefits of individual actions which are known to be effective in isolation, based on previous experiences. Such a foundation would be consistent with Koornstra et al. (2002) who describe methods for strategy development, potential for additional components and the contribution of individual components.

The strategies contain varying important background. However, the strategies do not describe a basis in theory or application of a proven methodology, required for a scientifically justifiable outcome. Commonly, road safety strategies include principles to provide background context to and justification for the strategy itself, but these are inconsistent between strategies studied. For instance, Vision Zero and the 2010 Australian Road Safety Strategy explicitly include the principle of 'shared responsibility' whereby everyone has an essential contribution to make traffic safer: politicians, planners, road maintenance organisations, municipalities, transport service providers, vehicle manufacturers, and road users. However, this principle is limited in the UK strategy by describing only formal agency responsibilities and is not explicit in the Dutch strategy. If such principles are valid, then existing and future strategies may be improved by the inclusion of other principles, from other strategies, not yet included.

During the course of the study, it was noted that certain other management approaches are applied to improve safety in other situations. For instance, safety management systems or risk management systems or by descriptions of the processes are widely used in general industry or other modes of transport. These approaches apply a risk assessment process by which hazards are thoroughly identified and mitigations developed and assessed prior to implementation. These approaches are generally developed and applied in conjunction with comprehensive communication with all relevant stakeholders. Safety improvement relies on innovation and application from other contexts to reduce risks.

As a result, additional principles should be investigated for inclusion in road safety strategies in future, including:

- any change to the system must take into account the full road safety effects which occur as other parts of the system change;
- a thorough risk minimisation process must be applied to achieve outcomes;
- broad based stakeholder participation enhances quality (including compliance) and acceptability;
- adoption of the number of people killed and seriously affected as the primary measure of safety;
- incorporation of innovation as the key to continuous improvement;
- strategy, policy and programme development and selection based on evidence; and
- comprehensive implementation.

It appears that the recent road safety strategies could have contributed to the observed improvements to road safety in the locations of application but remains to be proven. Further work needs to be done to assess the benefit of the fundamental constructs of the existing strategies. If the strategies are indeed valuable, the present study shows that there are similarities and differences in the fundamental constructs of the strategies which may have contributed, but which of the fundamental constructs, in whole or in part, is beneficial is not evident. Therefore, reaching an understanding of which parts of the strategies fundamental constructs contribute to the outcomes, and by how much was not the aim of the study.

Further development is needed, in order to fully apply the concepts of systems theory and safety models in road safety strategies. To ensure that all essential key components are clearly described is recommended as a first step to clarify existing general themes or principles. Subsequently, the interrelationships and interdependencies between the key components should be examined with respect to how they affect each other. Such scrutiny would enable an understanding of the contribution each key component makes to a particular road safety objective. This contribution will then determine the degree to which this key component is worthwhile and essential versus that objective. However, such scrutiny is likely to require the development to start at a conceptual level prior to any analysis at a detailed quantitative level. Eventually, such development will provide a thorough evidence base for the application of systems theory to improve road safety by high quality integrated, efficient and effective strategies.

References

Australian Transport Council, 2000. National Road Safety Strategy 2001–2010. ACT, Australian Transport Safety Bureau, Retrieved from http://www.atcouncil.gov.au/documents/NRSS_01_10.aspx.

Australian Transport Council, 2011. National Road Safety Strategy 2011–2020. Australian Transport Council, Canberra, Retrieved from http://www.atcouncil.gov.au/documents/NRSS_01_10.aspx.

Department for Transport, 2000. Tomorrow's Roads—Safer for Everyone. Department for Transport, London, Retrieved from http://londonroadsafety.tfl.gov.uk/www/downloads/tomorrows-roads_safer-everyone.pdf.

Evans, L., 2004. Traffic Safety. Science Serving Society, Bloomfield, MI.

Glendon, I., Waring, A., 1997. Risk management as a framework for occupational health and safety. J. Occup. Health Saf.: Aust. N.Z. 13 (6), 525–532.

Greibe, P., 2003. Accident prediction models for urban roads. Accid. Anal. Prev. 35 (2), 273–285, http://dx.doi.org/10.1016/S0001-4575(02)00005-2.

Haddon, W., 1980. Options for the prevention of motor vehicle crash injury. Isr. J. Med. Sci. 16 (1), 45–65.

Hale, A.R., Hovden, J., 1998. Management and culture: the third age of safety. A review of approaches to organisational aspects of safety, health and environment. In: Feyer, A.M., Williamson, A., 1 (Eds.), Occupational Injury: Risk, Prevention and Intervention. Taylor and Francis, London.

Hawksley, J.L., 1999. Developing a major accident prevention policy. J. Hazard. Mater. 65 (1–2), 109–121.

Hughes, B.P., Newstead, S., Anund, A., Shu, C.C., Falkmer, T., 2014. A review of models relevant to road safety. Submitted Accid. Anal. Prev., http://dx.doi.org/10.1016/j.aap.2014.06.003.

Johnston, I., 2010. Beyond "best practice" road safety thinking and systems management—a case for culture change research. Saf. Sci. 48 (7), 1175–1181, http://dx.doi.org/10.1016/j.ssci.2009.12.003.

Kaposi, A., Myers, M., 1994. Systems, Models and Measures. Springer-Verlag, Berlin.

Kjellén, U., 2000. Prevention of Accidents through Experience Feedback. Taylor and Francis, London.

Koornstra, M., Lynam, D., Nilsson, G., Noordzij, P., Pettersson, H.-E., Wegman, F., Wouters, P., 2002. Sunflower: A Comparative Study of the Development of Road Safety in Sweden, the United Kingdom and the Netherlands. Institute for Road Safety Research, Leidschendam.

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, http://dx.doi.org/10.1016/j.ssci.2009.10.006.

Leveson, N., 2004. A new accident model for engineering safer systems. Saf. Sci. 42 (4), 237–270, http://dx.doi.org/10.1016/S0925-7535(03)00047-X.

Leveson, N.G., 2011. Engineering a Safer World: Systems Thinking Applied to Safety. Massachusetts Institute of Technology, Cambridge.

Ministry of Transport and Communications, 1997. På väg mot det trafiksäkra samhället. Fritzes kundtjänst, Stockholm, Sweden.

Ottino, J., 2003. Complex systems. Am. Insitute Chem. Eng. 49, 292–299.

Perrow, C., 1984. Normal Accidents: Living with High-Risk Technologies. Basic Books, New York, NY.

Read, G.J.M., Salmon, P.M., Lenné, M.G., 2013. Sounding the warning bells: the need for a systems approach to understanding behaviour at rail level crossings. Appl. Ergon. 44 (5), 764–774, http://dx.doi.org/10.1016/j.apergo.2013.01.007.

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

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, http://dx.doi.org/10.1016/j.ssci.2012.04.011.

Standards Australia and Standards New Zealand, 2001. AS/NZS 4801:2001 Occupational Health and Safety Management Systems—Specification With Guidance For Use. Standards Australia, Sydney.

Standards Australia, 2006. AS4292.1 Railway Safety Management: Part 1 General Requirements. Standards Australia, Sydney.

Tingvall, C., Haworth, N., 1999. Vision Zero—An ethical approach to safety and mobility. In: Sixth ITE International Conference Road Safety & Traffic Enforcement, Beyond 2000, Melbourne, September 1999.

Tingvall, C., Lie, A., 2001. Vad är nollvisionen? några reflektioner kring nollvisionens grundprinciper. In: Spolander, K. (Ed.), Rationalitet och Etik I Samhällsekonomisk Analys och Nollvision. VINNOVA and NTF, Såstaholm, Sweden, p. 93-104.

Underwood, P., Waterson, P., 2013. Systemic accident analysis: examining the gap between research and practice. Accid. Anal. Prev. 55, 154–164.

Von Bertalanffy, L., 1968. General System Theory: Foundations, Development, Applications. Penguin, Braziller, Harmondsworth, Middlesex.

Waterson, P., 2009. A critical review of the systems approach within patient safety research. Ergonomics 52 (10), 1185–1195.

Wegman, F., Aarts, L., 2006. Advancing Sustainable Safety: National Road Safety Outlook 2005–2020. SWOV Institute for Road Safety Research, Leidenschendam.

Wegman, F., Aarts, L., Bax, C., 2008. Advancing sustainable safety: National road safety outlook for The Netherlands for 2005–2020. Saf. Sci. 46 (2), 323–343, http://dx.doi.org/10.1016/j.ssci.2007.06.013.

Wegman, F., Lynam, D., Nillsson, G. (undated). SUNflower: a comparative study of the developments of road safety in Sweden, the United Kingdom, and the Netherlands. Directorate General for Mobility and Transport, European Commission, Brussels. Retrieved from ⟨http://ec.europa.eu/transport/roadsafety_library/publications/sunflower_paper.pdf⟩.

Weinstein, M.B., 1996. Total quality approach to safety management. Prof. Saf. 41 (7), 18–22.

WHO, 2009. Global status report on road safety. World Health Organisation, Geneva.

WHO, 2010. Equity. In: Social Determinants and Public Health Programs. World Health Organisation, Geneva.

Wilson, J.R., 2014a. Fundamentals of systems ergonomics/human factors. Appl. Ergon. 45 (1), 5–13.

Wilson, J.R., 2014b. Systems ergonomics: looking into the future. Appl. Ergon. 45 (1), 3–4.